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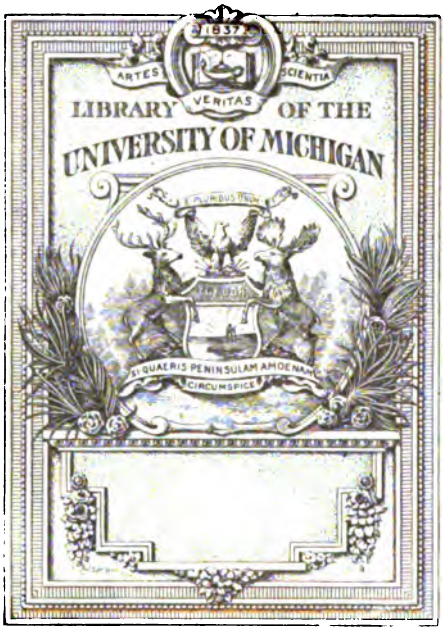

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 81.
MILTON WHITNEY, Chief.

A REPORT ON THE NATURAL PHOSPHATES OF TENNESSEE, KENTUCKY, AND ARKANSAS.

BY

WILLIAM H. WAGGAMAN,
Scientist in Chemical and Physical Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., October 30, 1911.

SIR: I have the honor to transmit herewith the manuscript of a report covering the phosphate-rock industry of Tennessee, Kentucky, and Arkansas, and to recommend that it be published as Bulletin No. 81 of this bureau. The report forms one of a proposed series of bulletins embodying the results of researches now being conducted by the bureau on the phosphates of lime. These substances form the basis of fertilizer manufacture the world over, and are of the utmost importance in the intensive handling of the soil.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON.
Secretary of Agriculture.

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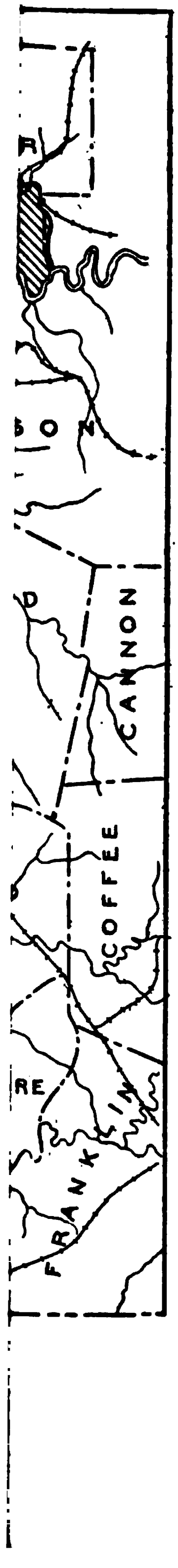
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A REPORT ON THE NATURAL PHOSPHATES OF TENNESSEE, KENTUCKY, AND ARKANSAS.

NATURAL PHOSPHATES OF TENNESSEE.

INTRODUCTION.

The phosphate deposits of Tennessee rank next in importance to those of Florida. Much work has been done in these fields and valuable geological and chemical reports have been published.

It is the purpose of this report to describe conditions in these fields, to outline the modern methods of mining and handling the rock, and to show what disposal is being made of the finished product and waste material or by-products of the industry.

The conditions in the Tennessee fields have changed considerably within the last few years, mining methods have improved, deposits of lower grade rock are being exploited, and many of the old mines and dumps are being reworked.

GEOGRAPHY AND TOPOGRAPHY.

Tennessee is well situated for the distribution of fertilizer material to the Southern and Middle Western States. Its phosphate deposits occur in what is known as the Central Basin of Tennessee (elevation, 600 feet) and in the valleys of the western part of the Highland Rim (elevation 1,000 feet) surrounding this basin. (See fig. 1.)

The Central Basin extends across the State from north to south, lying between the Cumberland Plateau on the east and the Tennessee River on the west. It covers an area of approximately 7,000 square miles of gently undulating country. The phosphate deposits have been developed only in the western part of this area, workable beds lying in parts of Sumner, Davidson, Williamson, Lewis, Maury, Hickman, and Giles Counties.

The main streams in the phosphate regions are the Cumberland, Duck, and Tennessee Rivers, but there are numerous creeks and tributaries of the Duck River that are of great importance in the development of the deposits, as sources of water supply for mining and handling the rock.

Both the Cumberland and Tennessee Rivers have been utilized for transporting phosphate rock, but mining in the vicinity of these streams has practically ceased and no recent shipments have been made. Considerable material will probably be shipped down the

Tennessee River in the near future, following the development of the white phosphate deposits of Perry and Decatur Counties.

Most of the mines are reached by the Louisville & Nashville, the Nashville, Chattanooga & St. Louis, and the Middle Tennessee Railroad.

GENERAL GEOLOGY.

All the exposed strata of these regions are of sedimentary origin. The phosphate occurs in rocks of Ordovician and Devonian age. Table I, compiled from the report of Hayes and Ulrich[1] on the Columbia quadrangle, which covers parts of Williamson, Hickman, Lewis, and Maury Counties, gives the stratigraphic position of the various phosphate beds and their relation to the overlying, surrounding, and underlying formations.

Table I.—*Geologic formations in the Columbia quadrangle, Tennessee.*

Age.	Formation.	Description.
Carboniferous	St. Louis limestone	Gray and blue cherty limestone.
	Tullahoma formation[1]	Very cherty shale.
Devonian	Chattanooga shale	Carbonaceous black shale. (Phosphate horizon.)
Silurian	Clifton limestone	Even-bedded, compact, gray or blue limestone.
	Fernvale formation	Soft green or brown shale with bands of crystalline limestone.
	Leipers formation	Knotty, earthy limestone and interbedded shale. (Phosphate.)
	Catheys formation	Knotty, earthy limestone and shale with bands of blue limestone. (Phosphate.)
Ordovician	Bigby limestone	Granular, crystalline, laminated phosphatic limestone. (Phosphate.)
	Hermitage formation	Shale with siliceous limestone below and phosphate limestone above. (Phosphate.)
	Carters limestone	Massive, compact, white or blue cherty limestone.
	Lebanon limestone	Thin-bedded, compact bluish limestone.

[1] Since the publication of the Columbia folio this formation has been correlated with the Fort Payne chert, the older name, and "Tullahoma" has been abandoned by the U. S. Geological Survey.

Table I shows four formations in the Ordovician rocks which contain phosphate beds. It must be understood, however, that these formations are not always in normal succession, some of them being absent in certain areas, nor are the beds always highly phosphatic. Local conditions during their deposition and subsequent changes have caused wide divergence in composition.

CLASSES OF PHOSPHATE.

There are three economically important classes of phosphate rock in Tennessee, namely, the brown phosphate, or Ordovician rock, which is divided by Hayes and Ulrich into several groups; the blue, or Devonian phosphate, of which there are several classes, and the white rock deposited from solution in caverns. The nodular and conglomerate phosphates, though widely distributed, are not found in sufficient quantities to be profitably mined by themselves. Each of the three classes mentioned will be treated separately.

---

[1] Columbia Folio, No. 95, U. S. Geological Survey, 1903.

BROWN-ROCK PHOSPHATE.

LOCATION OF DEPOSITS.

Workable deposits of brown-rock phosphate are found scattered over a very wide area, as many different beds occur in the several formations of Ordovician age. The most important are those in Sumner, Davidson, Williamson, Hickman, Maury, Lewis, and Giles Counties. Most of the mines are reached by the Louisville & Nashville and the Nashville, Chattanooga & St. Louis Railroads, but several of the deposits being worked in Hickman and Davidson Counties are several miles from the railroads. The brown-rock deposits west of Nashville, in Davidson County, and those of Sumner County, in the vicinity of Gallatin, have easy access to the Cumberland River.

GEOLOGICAL OCCURRENCE AND ORIGIN.

All of the Tennessee brown-rock phosphate occurs in rocks of Ordovician age. There are numerous phosphatic horizons in this series, some of which frequently occur so close together that they can be mined as a single bed. Taken in order of their stratigraphic succession, the phosphate bearing rocks are given in Table II.

TABLE II.—*Geologic formations in west-central Tennessee, which carry brown-rock phosphate.*

Age.	Formation.	County where found.
Ordovician	Leipers formation	Lewis, Hickman, Sumner.
	Catheys formation	Maury, Hickman (unimportant).
	Bigby limestone	Maury, Giles.
	Hermitage formation	Maury, Williamson, Davidson.

The deposits of brown phosphate are generally conceded to be formed by the leaching of phosphatic limestones by carbonated waters. The solution and removal of carbonate of lime has been attended by a diminution in thickness and consequent settling of the phosphatic strata. Some secondary deposition has also taken place in the pores and interstices of the leached mother rock.

The phosphate beds occur in two distinct forms, known as collar and blanket deposits. The first occurs where the horizontal phosphatic limestone stratum outcrops on the slope of a steep hill. The stratum passes through the hill but has been leached only at the outcrop, the overburden of younger rocks protecting the main part of the bed from the action of percolating waters. This class of deposit has proved very deceptive to the miner, who, finding the outcrop a very high grade phosphate rock, has tunneled into the hill to discover that the stratum passes rapidly to a phosphatic limestone.

The blanket deposits, on the other hand, sometimes cover wide areas. They usually lie near the surface of gently undulating hills where the underdrainage is favorable to their formation. Almost ideal conditions existed in the Mount Pleasant regions for the production of such deposits.

In this section the highly phosphatic Bigby limestone lies very near the surface and is underlain by an easily soluble fine-grained limestone through which the percolating water readily drained. The leaching began where the surface water gained access to the beds along the joint planes, but gradually worked through the entire mass, carrying away the carbonate of lime in solution and leaving the less soluble phosphate of lime.

The blanket deposits are always more or less wavy in their character, owing to the irregularity of the leaching. Large columns, bowlders, and cones of unaltered phosphatic limestone occur throughout these deposits. In Plate I, figures 1 and 2, are shown strata and bowlders of phosphatic limestone, with the leached brown phosphate occurring both above and below them.

There is also a secondary tufaceous brown phosphate which occurs in the Hermitage formation, but it occurs in very small quantities, is essentially a pocket formation, and is of no great economic importance.

According to Hayes and Ulrich,[1] the limestone from which the brown phosphate is derived was probably deposited in a sea so shallow that the bottom was affected by wave action and currents. These authors consider the deposits to be largely of organic origin and to consist of the remains of phosphatic and carbonaceous shellfish. The carbonate of lime was partly replaced by the phosphate, forming beds of more or less phosphatic limestone, which upon being elevated above the surface were further enriched as outlined above. Brown[2] and Ruhm[3] agree with Hayes and Ulrich in their theories as to the origin of the Ordovician phosphate.

PHYSICAL PROPERTIES.

The Ordovician phosphate varies considerably according to location. The beds derived from the different formations have definite characteristics which aid the geologist and mining engineer in identifying the horizon. The rock varies in color from a light gray to a deep chocolate brown and in texture from a porous rock, disintegrating into phosphatic sand, to a hard, close-grained rock very resistant to weathering. As a whole the rock is brown or gray and occurs in plates of varying thickness. The beds range in thickness from a few inches to 20 or 30 feet, with an average of 6 to 8 feet. The mean specific gravity of the Tennessee brown rock is about 2.8. The yield of phosphate per foot per acre is from 600 to 1,000 tons.

---

[1] Columbia Folio No. 95, U. S. Geological Survey, 1903.

[2] Engineering Association of the South. Trans., **15**, 93-94 (1903-4).

[3] Engineering and Mining Jour., **83**, 522 (1907).

In Table III are given the results of analyses of different types of brown-rock phosphate, the samples being taken in several localities:

TABLE III.—*Analyses of samples of Ordovician brown-rock phosphate from Tennessee.*

No.	Location.	Thickness of bed.	Geologic formation.	P_2O_5.	$Ca_3(PO_4)_2$.
		Feet.		*Per cent.*	*Per cent.*
3 and 5	Mount Pleasant, Maury County......	3	Bigby..................	34.50	75.42
46	Near Nashville, Davidson County....	4	Hermitage.............	34.32	75.02
70	Centerville, Hickman County.........	3	Leipers................	35.79	78.21
76	Near Centerville, Hickman County...	40	.....do..................	35.01	76.33
39	Near Gallatin, Sumner County.......	6	.....do..................	23.62	51.62
40	Wales Station, Giles County..........	8	Bigby (disintegrated).	31.11	67.98

METHODS OF MINING.

Only within the last few years have modern mining methods been employed in the Tennessee phosphate fields. For years the richest deposits of brown rock in the Mount Pleasant regions were worked by hand, and only when these deposits were considered to be nearly exhausted did the operators seem to realize the crudity, wastefulness, and inefficiency of the methods they were using. Even now a few small firms and farmers are employing the pioneer method of shaking out all rock not held by the tines of a potato fork and drying the larger pieces in the sun or on ricks of wood.

The larger operators have adopted much more thorough and economical methods of working the deposits. The overburden is first removed by steam shovels or scrapers, and the phosphate rock, together with its matrix, dug out with picks and forks, loaded into tramcars, and hauled to the washer, where it is put through a cleansing process described below. In the vicinity of Centerville they have installed the hydraulic system of mining which has been used so successfully in the Florida land pebble regions. By employing a screen to prevent large pieces of rock from entering the centrifugal pump this method is expected to prove very satisfactory. The Tennessee phosphate regions have distinct advantages over those of Florida for hydraulic mining, as the Tennessee product occurs in the hills, where the overburden can be disposed of by gravity. The rock itself does not have to be pumped to a great height, as is the case in many of the Florida mines, where the pits are so far below the level of the washer plant. Plate II, figure 1, shows the method of mining brown-rock phosphate.

The modern Tennessee washing plants differ considerably in some features, but the general scheme of separating the phosphate from its impurities is the same with all of them. The phosphate rock, together with the matrix in which it is frequently embedded, is brought from the mines in tramcars, hauled to the top of the washer, and dumped into a hopper. Streams of water are played upon the mass, washing the material down to a crusher, which breaks up the larger lumps of rock. From this point it either goes through a log washer similar to that employed in the Florida phosphate fields,[1] or is conveyed over a series of screens by a kind of chain scraper.

The material passing through these screens then goes to the revolving rinser, where it is thoroughly sprayed. The portion passing through the half-inch perforations of the rinser falls into a hopper, is taken up by pumps, and passed through a series of settling tanks, being finally discharged into the draining bins. After the water has partly drained off the washed product is drawn out and sent to the driers. Plate II, figure 2, shows one of the most modern types of phosphate washers.

Where the log washer is employed, the backwash, together with the overflow from the settling tanks, is led through troughs fitted with riffles to catch the finely divided phosphate. The clay and other impurities held in suspension with very finely divided phosphate is finally discharged into waste ponds. This method of washing has proved so efficient that many of the old deposits are being reworked and a very high grade product obtained.

In Table IV a comparison is made of the coarser rock which was saved by the old mining methods and the fine material formerly thrown out, but which modern washer plants have now made it profitable to mine.

TABLE IV.—*Analyses of coarse and fine, washed, Tennessee brown phosphate.*

Location.	Coarse fragments.		Rock fragments, less than one-half inch diameter.	
	P_2O_5	$Ca_3(PO_4)_2$	P_2O_5	$Ca_3(PO_4)_2$
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Charleston, S. C., Mining & Manufacturing Co., Mount Pleasant, Tenn.	33.50	73.23	34.32	75.01
Volunteer State Co., Centerville, Tenn.	35.01	76.33	33.23	72.64
Mount Pleasant, Tenn., International Agricultural Corporation plant	36.91	80.65	35.72	78.05

The old kiln method of drying phosphate on ricks of wood is still employed to some extent in the brown-rock region, but is used only for the larger plates or fragments of rock. A few small operators still dry their rock in the sun, but the output of material dried in this way is very small.

Most of the rock is dried in rotary cylinders, which are so largely employed in the pebble regions of Florida.[2] Some of the miners prefer to feed their phosphate rock into the hottest end of the drier—that is, the end in which the flames and gases of combustion enter—while others introduce the phosphate into the cooler end of the cylinder and allow it to work toward the hotter end. The latter method seems on the whole more efficient and economical, since the partly dried rock does not come in contact with atmosphere highly charged with moisture, and there is also probably less danger of loss of finely divided rock through the stack. Kentucky coal is used as fuel.

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[1] Waggaman, Bul. No. 76, Bureau of Soils, U. S. Dept. Agr., 1910.

[2] Waggaman, Bul. No. 76, Bureau of Soils, U. S. Dept. Agr.; Menninger, C. G., Eng. News, 60, 1908.

COST OF PRODUCTION.

The cost of preparing brown-rock phosphate for the market has increased considerably in recent years. When the rock was first mined no plant was required to treat the phosphate, hand labor was employed, and a few rough sheds were erected in which to store or dry the material. At that time thousands of tons were mined at a cost not exceeding 75 cents per ton.

With the increased cost of labor and fuel and the expense of erecting washing and drying plants, the cost of production has advanced greatly. In the Mount Pleasant district, where the old deposits are being reworked, and in Giles County, where the phosphate is in a disintegrated condition, much waste material has to be handled to obtain a high-grade product. It is also necessary to remove a much heavier overburden than formerly to reach the phosphate deposits. Many of the operators find it profitable to remove 4 feet of overburden for every foot of underlying phosphate. The average cost of taking off this overburden is 15 cents per cubic yard, though it is claimed that where hydraulic methods are employed it can be removed at a much lower figure.

On account of these numerous factors the average cost of producing high-grade rock for the fertilizer trade is not far from $2.50 per ton.

MARKETING.

The current freight rates from the principal mining districts in the brown-rock regions to the manufacturing cities and markets are given in Table V.

TABLE V.—*Freight rates on phosphate rock (lump rock) per long ton.*

Location of deposit.	Destination.	Rate per ton.
Mount Pleasant, Columbia, and vicinity; Wales and vicinity, Franklin, to	Cincinnati, Ohio	$2.50
	Cleveland, Ohio	3.80
	Columbus, Ohio	3.40
	Louisville, Ky	2.25
	Indianapolis, Ind	3.10
	Atlanta, Ga	2.45
	Montgomery, Ala	1.75
	Savannah, Ga	3.75
Gallatin and vicinity to	Cincinnati, Ohio	2.25
	Cleveland, Ohio	3.55
	Columbus, Ohio	3.15
	Louisville, Ky	2.00
	Indianapolis, Ind	2.85
Centerville and vicinity to	Cincinnati, Ohio	2.50
	Nashville, Tenn	1.75

Ton of 2,000 pounds.

Most of the brown-rock phosphate mined in Tennessee is disposed of in this country, though a considerable quantity of the highest grade—rock containing from 78 to 80 per cent $Ca_3(PO_4)_2$—is shipped abroad.

The fertilizer trade (manufacturers of acid phosphate) demands a rock containing not less than 72 per cent bone phosphate of lime ($Ca_3 (PO_4)_2$) and not more than 5 per cent iron and alumina. This produces an acid phosphate containing 16 per cent available phosphoric acid.

Within the last few years the sales of ground-rock phosphate for direct application to the field have grown considerably. Excellent results have been reported from its use at the Ohio and Illinois experiment stations and from individual farmers. Several companies are handling this product exclusively. The rock is ground to varying degrees of fineness. One company has two grades; No. 1 is ground so that 90 per cent will pass a 60-mesh sieve and No. 2 ground so that 95 per cent will pass a screen containing 100 meshes to the inch. The ground rock is sold on a guaranty of 60 to 65 per cent bone phosphate of lime ($Ca_3(PO_4)_2$) and shipped chiefly to States in the Middle West.

In Sumner and Hickman Counties new phosphate fertilizers are being prepared. The processes are patented and the manufacturers claim that they obtain a product containing fully as much phosphoric acid as superphosphate, without the objectionable feature of free acid. Under these new processes rather low grade rock can be used.

WASTE MATERIAL.

Within the last few years the main sources of waste in the brown-rock phosphate fields have been largely eliminated. When phosphate was first mined in the Mount Pleasant district probably half of the rock was thrown away. Much of this will never be recovered, as it has become mixed with foreign matter and covered by overburden too heavy to make reworking commercially practicable. A large proportion of the Mount Pleasant deposits, however, are now being worked over. Modern washer plants save upward of 75 per cent of the phosphatic material, recovering much of the finely divided or disintegrated rock. The operators state they can hold and cleanse material fine enough to pass a 60-mesh sieve.

Considerable finely divided phosphate is discharged into the waste ponds. Samples of material taken where the wash water enters these ponds are found to be quite rich in phosphoric acid, but the quality of the deposited residue falls off as the middle and far end of the pond is reached, since the heavier particles, which are mainly phosphate rock, have settled out. Part of these waste ponds can and doubtless will be worked over to advantage.

In putting the rock through the mechanical dryer considerable phosphate dust is carried up the flue and out of the stack by the powerful draft. Many of the stacks are now provided with hoods and baffles to catch these "floats." Weather conditions affect the amount of material thus carried up the flues, but, roughly figured, about 2 tons of "floats" are saved by these hoods for every 100 tons of rock charged to the dryers.

The limestone "horses," or unleached phosphatic limestones, occurring in most of the brown-rock phosphate beds frequently contain a high percentage of phosphoric acid. No attempt has been made as yet to utilize these bowlders, although they would be valuable when ground, as they contain a considerable quantity of lime phosphate mixed with lime carbonate. Under the present method of mining the phosphate is dug from around these bowlders and the pits are then either abandoned or filled in with overburden from adjoining deposits. These bowlders could be removed, broken up, and crushed at small cost, and would prove of considerable value as fertilizer material.

Another method of utilizing these phosphatic limestones would be to burn them in a kiln, afterwards slaking them with steam or hot water. There is frequently sufficient carbonate of lime present to make this a practical means of disintegrating the rock.

In Table VI the phosphate content of a number of samples of phosphatic limestone before and after burning are given. These samples were first dried for several hours at 100° C. and then analyzed. They were then heated to the highest temperature obtainable with a blast lamp until they ceased to lose in weight, and again analyzed.

TABLE VI.—*Analyses of phosphatic limestone, underlying phosphate beds, and bowlders before and after burning.*

No.	Location.	Content of P_2O_5.	
		Before burning.	After burning.
		Per cent.	*Per cent.*
2	Mount Pleasant, Tenn., underlying limestone	16.05	21.15
4	.....do	9.48	11.12
6	.....do	19.43	21.42
8	.....do	18.30	23.86
11 W	Near Mount Pleasant, Maury County	12.53	21.15
47	6 miles west of Nashville, Davidson County	22.97	27.05
65	2 miles north of Centerville, Hickman County	14.69	19.75
75	.....do	16.32	17.72

In Table VII there are given the results of some experiments carried on in cooperation with L. R. Coates, of Baltimore, Md., the object of which was to test the slaking properties of phosphatic limestones after heating to various temperatures.

The samples grouped opposite A were burned at the temperatures indicated in column 2 and sent to the laboratories of this bureau. Here they were then slaked and sifted, and the percentages of the several sized particles determined. Each was then analyzed for phosphoric acid.

The samples under B were all burned and analyzed in the physical laboratory of the H. S. Spackman Engineering Co., Philadelphia, Pa. It is understood they were ground before being burned. This fact no doubt accounts for the small percentage of nodules in the samples.

TABLE VII.—*Mechanical and chemical analyses of phosphatic limestone after burning and slaking.*

1	2	3	4	5						6
Sample No.	Temperature.	Time of heating.	Loss on heating (per cent).	Percentage of separates after heating and their phosphoric acid content.						CaCo$_3$ in nodules (per cent).
				Nodules.	P$_2$O$_5$.	0.1–0.25 mm.	P$_2$O$_5$.	0.1 mm.	P$_2$O$_5$.	
A	*C°*									
Check for 1 and 2.	....	Not heated	....	100	22.80	....	......	......	......	....
1	800–812	7 hours	15.30	55+	27.24	26+	27.96	18+	24.00	7.45
2	909–914	do	15.50	38+	29.04	28+	28.44	33+	24.28	5.65
Check for 3.	....	Not heated	....	100	24.56	....	......	......	......	....
3	700–705	7 hours	8.40	78+	25.88	13+	29.72	9+	26.24	26.86
B										
Check for 4, 5, 6, and 7.	....	Not heated	....	......	24.56	....	......	......	......	....
4	700	15 minutes	18.15	4+	18.00	36+	27.16	58+	24.68	....
5	800	do	18.23	1+	26.96	28+	29.16	69+	24.28	....
6	900	do	18.90	6+	25.20	41+	26.44	52+	22.08	....
7	1,000	do	18.95	3+	26.76	43+	28.60	53+	22.16	....

In every instance (except two, where the temperature was only 700° C.) the percentage of phosphoric acid is lower in the finest of the three grades of separates. This is to be expected from the character of the rock, since the free lime in slaking readily disintegrates. The figures in Table V, *A*, seem to indicate that slaking takes place much better when the phosphatic limestone has been heated to 900° C. or higher.

Another source of waste is at the picking belt, where the clay balls, flint, and limestone are picked out by hand and thrown away. Unfortunately a poor class of labor is usually employed for this purpose, and much good phosphate is lost in the operation.

In Table VIII are given the analyses of the various samples of phosphatic material, much of which is wasted in preparing the rock for the market.

TABLE VIII.—*Analyses of material lost in the pioneer methods of mining brown-rock phosphate.*

No.	Location.	Description.	SiO_2.	Fe_2O_3-Al_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
12	Arrow mine, Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Material discharged into waste pond; sample taken close to mouth of trough.[1]	5.77	4.19	34.32	75.01
22	Property of International Agricultural Corporation at Mount Pleasant, Tenn.	Phosphate, sand, and mud discharged into waste pond.	....	....	27.32	59.70
20	Property of Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Phosphate, sand, and mud, formerly thrown away, now being worked over.	16.65	6.48	28.22	61.66
16	Arrow plant of Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Material thrown from picking board—clay balls containing limestone, flint, and phosphate.	35.40	6.17	22.49	49.14
21	Blue Grass plant of International Agricultural Corporation, Mount Pleasant, Tenn.	Sample of floats saved by placing hood over stack—phosphate dust containing carbon.	....	....	30.51	66.67

[1] This material will no doubt be worked over and much of the phosphate recovered.

PRESENT CONDITION OF THE INDUSTRY.

There are fully 30 companies which own brown-rock phosphate property in Tennessee, but during the early part of 1911 only 15 of these were actually engaged in mining operations. The combined capacity of the 15 operating plants was about 900,000 tons per annum, but few were running full time and many only intermittently.

Brown-rock mining is being carried on at or near Mount Pleasant, Columbia, and Southport, in Maury County; near Gallatin, in Sumner County; at Wales Station, in Giles County; near Centerville, in Hickman County, and near Ewells Station, Williamson County.

After several years of depression the brown-rock phosphate industry during 1910 showed considerable activity, resulting in a substantial gain over 1909 in the material marketed. The control of the fields, however, is passing rapidly into the hands of the large fertilizer corporations. These companies have installed modern washer plants and are working deposits which the small operator was unable to handle with limited capital. Mining operations, however, have not resumed their former activity. This is due both to the increased cost of labor and the greater expense of handling the remaining deposits of phosphate. The enormous development in the last few years of the Florida pebble phosphate is also accountable for the falling off in the production of Tennessee rock.

The average price of brown-rock phosphate (72 per cent) f. o. b. mines is about $3.75 per ton. Apparently the price of this material has reached its level, and wide variations from the price given are not to be anticipated, barring some unusual and unexpected development in the industrial or labor worlds.

Table IX is a summary taken from the report of F. B. Van Horn[1] and shows the production of Tennessee phosphate during the last six years.

TABLE IX.—*Production of phosphate rock of the several classes in Tennessee from 1905 to 1910, inclusive.*

[Long tons.]

Year.	Brown rock.	Blue rock.	White rock.	Year.	Brown rock.	Blue rock.	White rock.
1905	438,139	44,031	689	1908	374,114	79,717	1,600
1906	510,705	35,669	1,303	1909	266,298	66,705	....
1907	594,594	38,993	5,025	1910	329,382	68,806	....

FUTURE OF THE INDUSTRY.

A few years ago the life of the Mount Pleasant phosphate fields was considered limited to six or seven years at most. With the advent of new machinery and modern mining methods many deposits which were regarded as exhausted promise to yield as much high-grade rock as has been removed in past years. Many of the rich deposits are still practically untouched, and it is safe to assume that the brown-rock fields will continue to produce a large tonnage for many years.

BLUE-ROCK PHOSPHATE.

LOCATION OF DEPOSITS.

The important deposits of blue-rock, or Devonian, phosphate in Tennessee lie along Leatherwood Creek, in the western part of Maury County, south and east of Centerville, on both sides of Swan Creek, in Hickman County, and in the eastern part of Lewis County.

The mines are reached by the Louisville & Nashville, Nashville, Chattanooga & St. Louis, and Middle Tennessee Railroads. The rock is usually dried and then shipped to various points in the South and Middle West. The Duck River is the only navigable stream convenient to the blue-rock fields. Practically no phosphate has been shipped on this river in recent years.

GEOLOGICAL OCCURRENCE.

The blue-rock phosphate belongs to the Devonian period and occurs in the geologic formation known as the Chattanooga shale. The beds vary in thickness up to 4 feet and differ widely in their content of phosphoric acid in different locations.

The phosphate stratum is usually overlain by a massive blue-black shale or slate, 3 feet or more in thickness, containing at its base phosphatic nodules, and is underlain normally by Silurian limestone.

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[1] Production of Phosphate in 1910, Mineral Resources, U. S. Geological Survey.

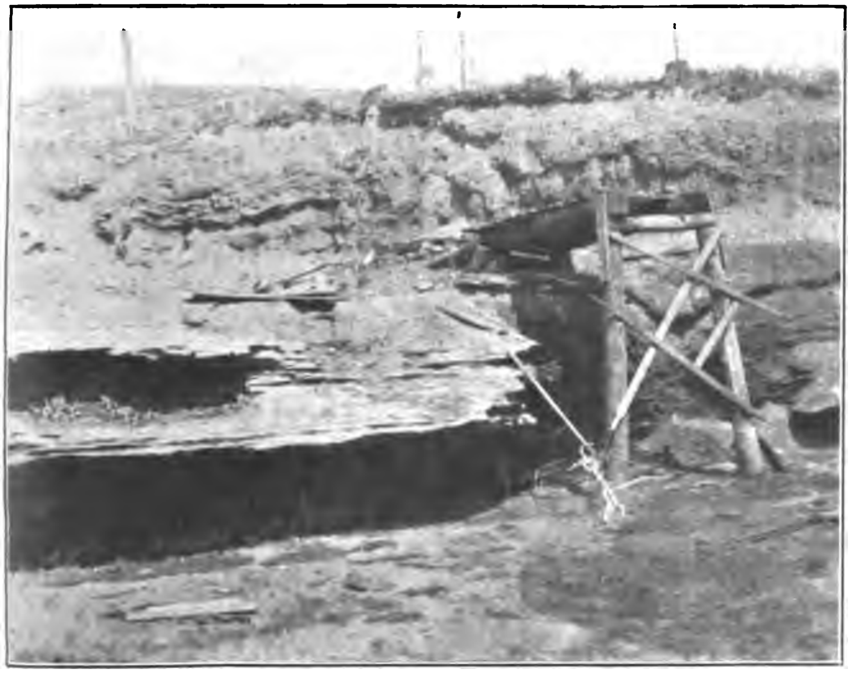

FIG. 1.—STRATUM OF PHOSPHATIC LIMESTONE OCCURRING IN PHOSPHATE BEDS.

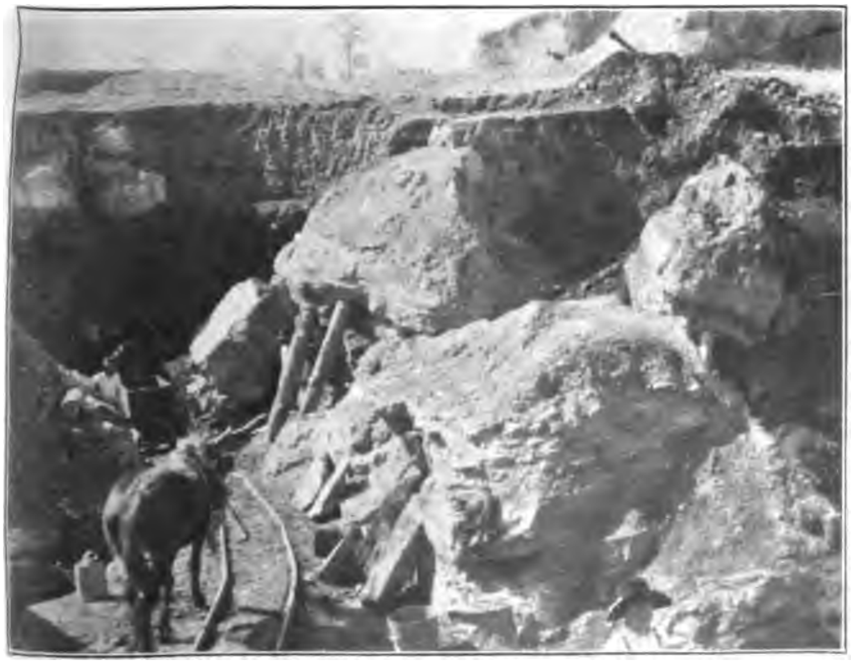

FIG. 2.—BROWN-ROCK MINING, SHOWING BOWLDERS OF PHOSPHATIC LIMESTONE.

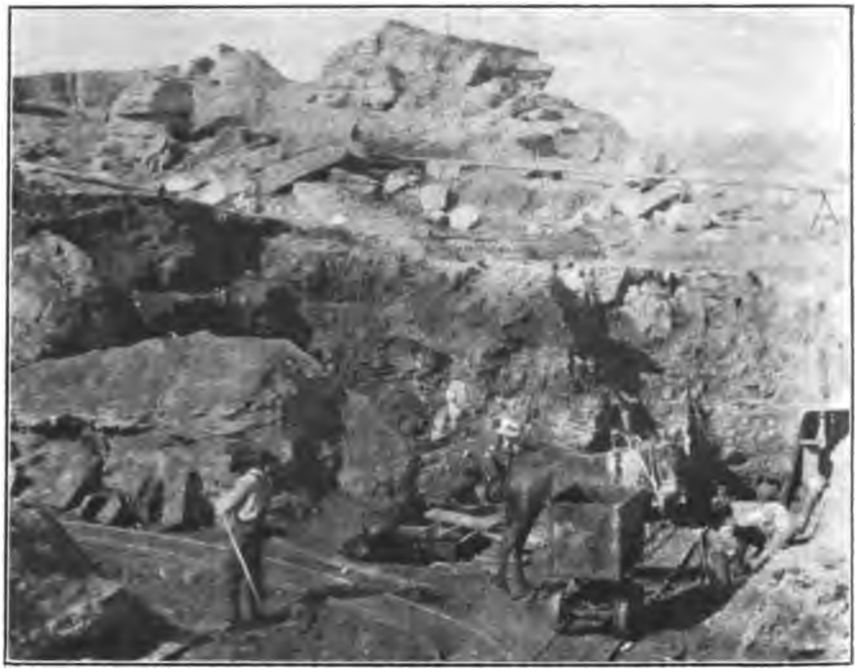

FIG. 1.—BROWN-ROCK MINING, CENTERVILLE, HICKMAN COUNTY, TENN.

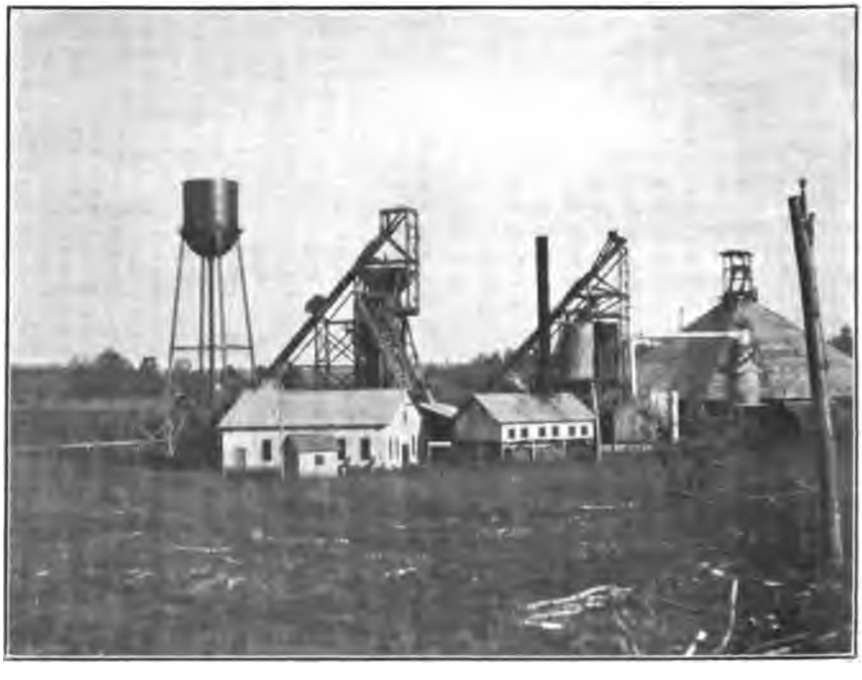

FIG. 2.—ONE OF THE MOST MODERN TYPES OF PHOSPHATE PLANTS, MOUNT PLEASANT, TENN.

Frequently an unconformity exists which brings the Devonian phosphate directly over the brown Ordovician rock. Under these conditions mining should be carried on very profitably.

The analyses of some typical sections of phosphate from areas where such conditions occur are given in Table X.

TABLE X.—*Analyses and descriptions of phosphate beds from localities where the blue rock directly overlies the brown phosphate of the Leipers formation.*

No.	Location.	Thickness of strata.		Description.	Analysis.	
					P_2O_5.	$Ca_3(PO_4)_2$.
		Ft.	*in.*		*Per cent.*	*Per cent.*
68	Blue Buck mines, 6 miles southeast of Centerville, Tenn.	0	9	Coarse, hard blue rock	24.80	54.20
69	.....do		9	Fine-grained, hard blue rock	27.91	60.98
70	.....do	2	6	Brown phosphate (Leipers formation).	35.79	78.21
60	Corn Belt Phosphate Co., 8 miles east of Centerville.	1	3	Coarse, oolitic gray rock	25.25	55.18
61	.....do		8	Close-grained, hard blue rock	32.95	72.01
66	.....do	1	6	Brown disintegrated phosphate (Leipers formation).	32.40	70.82
71	Meridian Fertilizer Factory, 2 miles south of Centerville	1	8	Coarse oolitic blue rock (sampled in tunnel).	26.44	57.79
72	.....do	1	2	Fine-grained, hard blue rock (in tunnel).	36.66	80.11
([1])	.....do	....	....	Brown phosphate (Leipers formation).	....	....

[1] No sample collected.

According to Hayes and Ulrich[1] the blue-rock phosphate was laid down under conditions somewhat similar to those under which the Ordovician phosphate was deposited, except that the shellfish and organisms from which the deposits are in part derived were more highly phosphatic than those existing in Ordovician times, and consequently the deposits required no subsequent leaching to make them of economic value. Another important factor in the formation of the richer deposits of blue phosphate, according to these authorities, is the highly phosphatic Leipers limestone, which in places directly underlies the Devonian phosphate, and which through leaching and subsequent disintegration has given the blue rock much of its substance.

The beds of the highest-grade phosphate, therefore, are of both primary and secondary origin, consisting of the rolled and leached fragments of Ordovician limestone and the phosphatic remains of Devonian life.

PHYSICAL PROPERTIES.

The physical properties of blue-rock phosphate differ according to the conditions of its deposition. The unweathered rock varies in color from a blue black to light gray, depending on its content of organic matter, and in texture from a hard, close-grained, massive calcareous rock to coarsely oolitic, loosely cemented material, very readily broken up. In general the phosphate-bearing formation may be described as a bluish-gray rock, composed of flattened ovules and the waterworn casts of phosphatic shells. In the fresh state the rock is very hard and difficult to grind. It weathers upon exposure into a rusty-yellow material. The average specific gravity of the rock is about 2.87. This means that a stratum 1 foot thick will run about 3,200 tons per acre.

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[1] Loc. cit.

The blue rock, as a rule, has a lower content of phosphoric acid than the brown, but this objection is largely offset by the fact that it contains less iron and alumina than the brown rock.

In Table XI the analyses of several types of blue-rock phosphate are given, with their more prominent physical characteristics.

TABLE XI.—*Analyses of different types of Tennessee blue-rock phosphate from various localities.*

No.	Location.	Description.	Analysis.	
			P_2O_5	$Ca_3(PO_4)_2$
			Per cent.	*Per cent.*
49	Leatherwood Creek, Maury County..	Hard blue rock, partly weathered to rusty brown.	31.39	68.58
54	Blue Buck mines, 6 miles southeast of Centerville.	Hard, close-grained blue rock.........	32.21	70.39
56	.....do..............................	Hard, close-grained blue rock (high grade).	36.79	80.41
58	.....do..............................	Coarse, gray oolitic rock, yet not as hard as No. 58.	31.66	69.19
59	.....do..............................	Kidney phosphate, occurring in slate above blue-rock phosphate.	33.86	73.99
60	Corn Belt Phosphate Co., 8 miles east of Centerville.	Coarse, oolitic gray rock, overlying blue rock.	25.25	55.18
61	.....do..............................	Hard blue rock, underlying No. 60....	32.95	72.01
71	Meridian Fertilizer Factory, 2 miles south of Centerville.	Coarse, oolitic blue rock (unweathered)	26.44	57.79
73	.....do..............................	Coarse, oolitic blue rock (weathered), overlying high-grade blue rock.	28.82	62.98
72	.....do..............................	Fine-grained, hard blue rock (sampled in tunnel).	36.66	80.11
74	.....do..............................	Fine-grained, hard blue rock (sampled outside tunnel).	35.75	78.12
123	Mayfield mine, Gordonsburg, Lewis County.	Kidney phosphate, embedded in slate roof.	27.58	60.27
124	do..............................	Fine-grained, hard blue rock (high grade).	36.20	79.11

METHODS OF MINING.

The blue-rock phosphate is mined by first stripping around the face of the hill, then drifting in on the stratum as the overburden becomes too heavy to remove. The blue shale or slate directly overlying the phosphate forms, as a rule, an excellent roof, requiring no great amount of timbering for its support. Owing to its hardness, the rock is loosened by blasting and then broken up with picks. Compressed-air drills are now largely used in mining. The material is loaded into tramcars and wheeled or drawn by mules to the drying and crushing plant, where it is prepared for shipment. No washing is necessary for the bedded blue-rock phosphate. In Plate IV, figure 1, is shown the method of mining blue-rock phosphate.

The rock is dried both in kilns and in mechanical dryers, such as described under brown-rock phosphate. As it comes from the mines the rock contains a rather low percentage of moisture, and some of the miners deem it unnecessary to dry it at all. Since it contains both carbonate of lime and organic matter, the burning or drying process serves to increase the percentage of phosphoric acid in the finished product.

COST OF PRODUCTION.

In comparing the cost of mining blue-rock phosphate with that of brown there are a number of factors to be considered. Tunneling is more expensive than mining by open cut, except where the overburden is very heavy or composed of a hard rock like that usually overlying the Devonian phosphate.

The blue rock must be blasted or drilled out, whereas the brown-rock phosphate can be removed with pick and shovel. The blue rock does not have to be washed and contains but little moisture, while much of the brown rock (as mined to-day) must be put through an elaborate cleansing process, during which considerable foreign material is handled for each ton of phosphate produced. In addition, a large quantity of fuel must be consumed to remove the water. Formerly the cost of mining blue rock was greater than that of mining brown, but the expense at present is nearly the same, approximately $2.50 per ton.

One point in favor of blue-rock mining is that work can go on in the tunnels during wet weather, while the brown-rock mines are forced to suspend work.

DISPOSAL OF PRODUCT.

Although some specimens of blue-rock phosphate will run as high as 78 to 80 per cent of bone phosphate of lime, which is the grade demanded for export, the average grade of the rock is not usually more than 70 to 72 per cent. Most of the blue-rock phosphate mined in Tennessee is consumed in this county in the manufacture of acid phosphate.

FREIGHT RATES.

Since much of the blue rock is found in the same localities as the brown, the freight rates given on page 11 also apply to this product.

EXTENT OF OPERATIONS.

Extensive development work in the blue-rock region has been done along Swan Creek and its tributaries in Hickman County, along Leatherwood Creek in Maury County, and at Gordonsburg in Lewis

County, but only at the latter place is much mining going on at present.

According to Van Horn,[1] the total quantity of blue-rock phosphate produced from 1905 to 1910 is 333,921 tons.[2] The annual output is given in Table IX.

PRESENT CONDITION OF THE INDUSTRY.

Five companies are mining blue-rock phosphate at the present time, but only one of these has a large annual output. The production of this class of phosphate is falling off considerably. This is due to a number of causes: First, many of the deposits are of an uncertain character. Sometimes the phosphate stratum thins out to almost nothing when followed into the hills, while in other localities the beds may grow thicker but become so poor in phosphoric acid that the rock is of no commercial value. Second, the enormous development of the Florida pebble phosphate fields during the last few years has caused a decline through competition. Third, new methods of handling the disintegrated brown-rock phosphate, formerly considered waste, have caused a revival in these fields at the expense of the blue-rock industry.

FUTURE OPERATIONS.

With the exception of the high-grade blue-rock deposits and those beds which rest directly on the brown rock, so that both can be worked together, the blue phosphate will probably not be extensively mined for a number of years. The operators have so often been deceived in what promised to be extensive high-grade, blue-rock deposits, but which subsequently "pinched out," that they prefer to await better prices before undertaking to mine strata of uncertain composition. Should the price of phosphate advance, it will doubtless cause renewed activity in these fields.

White-Rock Phosphate.

LOCATION OF DEPOSITS.

The white phosphate rock of Tennessee so far exploited occurs in Perry and Decatur Counties.

In the former county[3] the mines are located at Toms Creek, from 5 to 6 miles east of the Tennessee River. In Decatur County[4] the phosphate has been developed along the tributaries of Beech River, between Parsons and Decaturville. The mines are from 6 to 8 miles west of the Tennessee River and from 3 to 4 miles from the Nashville,

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[1] Production of Phosphate Rock in 1910. Mineral Resources, U. S. Geological Survey.

[2] This includes a small tonnage from Arkansas.

[3] Hayes, Ann. Report, U. S. Geological Survey, Part III, 1899–1910.

[4] B. Eckel, Bul. 213, U. S. Geological Survey, 418–419 (1903).

Chattanooga & St. Louis Railroad at Parsons, Tenn. There is a good wagon road between Parsons and Decaturville.

Although the deposits of white phosphate occur mostly in pockets and can not be expected to have any great lateral extent, some of more or less importance have been reported at several widely separated localities in Perry and Decatur Counties.

GEOLOGICAL OCCURRENCE AND ORIGIN.

The white phosphates are all of secondary origin, and belong to a much more recent geologic period than the Silurian and Devonian rocks with which they are associated. Hayes[1] divides them into three classes, namely, the stony, breccia, and lamellar phosphate. The first two classes, though widely disseminated, are in quantities too small and too thoroughly mixed with chert and foreign matter to be profitably mined. Fortunately, the lamellar phosphate is not only the richest, but the most plentiful of the three varieties. It is seldom found as an outcrop, but is encountered as the beds are followed into the hills. According to Hayes, it was deposited from solution in caverns in the upper Silurian limestone, the character of the rock indicating that the deposition frequently took place under hydrostatic pressure. As the limestones above these caverns were gradually dissolved by percolating and running water, the overlying strata settled down on the phosphate beds, causing a breaking up of the phosphate layers and more or less mixing with the chert fragments and residual clays from the overlying formations.

The phosphate is usually overlain by 3 to 8 feet of blue or yellow clay carrying phosphate fragments, which in turn is overlain by several feet of red and yellow clay containing limestone bowlders and fragments of chert.

PHYSICAL PROPERTIES.

Much of the white phosphate of Tennessee resembles the hard-rock phosphate of Florida. The breccia variety consists of chert fragments embedded in a matrix of high-grade phosphate, while the stony phosphate consists of siliceous skeletons formerly filled with carbonate of lime, but now containing phosphate. Both of these grades, unless they are separated from the associated chert, are too low in phosphoric acid to be of much importance.

The lamellar variety is very high grade material. It occurs in plates of various thicknesses, which are frequently cemented together, forming large bowlders weighing many tons. These plates vary from white or cream colored to pink and deep red. Some of the layers are rather porous, but the rock as a whole is close grained, very hard, and frequently coated with a thin, lustrous layer of precipitated phosphate. Picked samples of the lamellar phosphate will run as high as 85 to 90 per cent bone phosphate of lime, and there is little difficulty in obtaining rock in carload lots which will grade from 72 to 78 per cent.

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[1] Mineral Resources, Part 4, 623-630, 1894-95; Ann. Report U. S. Geological Survey, 1899-1900, Part III, 484-485. Ann. Report U. S. Geological Survey, 1895-96, Part II, 236-250.

A number of different types of white phosphate were collected when the author visited these fields early in 1911, but unfortunately through some mistake the various types were mixed and analyzed as one sample. Some of the samples contained large quantities of chert, so that the analysis of the whole, though given below (No. 82) is of little value. Some other phosphate analyses of the Tennessee white rock from Perry and Decatur Counties are given which show that much of this material is of excellent quality and well suited for the manufacture of superphosphate.

METHODS OF MINING.

The Tennessee white phosphate has been mined by both open cut and by tunneling. The former method has been employed wherever the character and depth of overburden permit, but the overload is frequently so heavy as to render its removal impracticable, and under such circumstances tunneling is resorted to. Owing to the loose character of the overlying clay, extensive timbering is required in the tunnels and much of the white phosphate embedded in the clay above can not be economically recovered.

As the phosphate is extremely hard and often occurs in very large bowlders, it is usually loosened by blasting, broken up with picks, and then loaded into tramcars and sent to the plant to be crushed into pieces of uniform size.

The objectionable features of tunnel mining and hardness of the rock are largely offset by the fact that it is unnecessary either to wash or dry the white phosphate to obtain a product grading from 72 to 75 per cent of bone phosphate of lime. The results of analyses are given in Table XII.

TABLE XII.—*Analyses of samples of Tennessee white-rock phosphate.*

No.	Location.	Description.	Analyst.	Analysis.			
				SiO_2.	Fe_2O_3 Al_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
82	Toms Creek, Perry County.	Phosphate and chert....	C. C. Stark....	....	....	26.77	58.49
85	.....do.....................	Phosphate from storage bins.	.....do........	6.55	2.71	32.76	71.00
86	Beech River Phosphate Co., Decatur County.	High-grade lamellar phosphate.	.....do........	7.56	3.48	34.49	75.36
87	Bowlder washed out of limestone cavern on Beech River, Decatur County.	Cherty white phosphate.	.....do........	47.09	3.90	18.61	40.66
	Perry County............	Picked sample..........	L. P. Brown..	....	1.38	37.89	82.74
	.....do.....................	Sample of shipment.....	.....do........	....	2.57	35.32	77.14
	Decatur County..........	Average of three small shipments.	.....do........	....	2.90	33.88	73.89

COST OF PRODUCTION.

On account of the uncertain character of these deposits and the varying factors influencing the class of mining employed, it is difficult to estimate the average cost of preparing the white phosphate for market. Moreover, no mining has been done in these fields for several years, during which time both labor conditions and mining methods have changed.

Brown[1] states that the average cost of production should be slightly below that of Florida hard-rock phosphate. Considering the various factors enumerated above, it is probable that the cost of preparing the white rock for the market is somewhat higher than that of the Tennessee blue rock.

WASTE MATERIAL.

The clay associated with and directly overlying the lamellar phosphate frequently contains many small fragments of high-grade rock. In the tunnel method of mining this phosphate is lost. Even when mining with open cut much of this phosphatic material is wasted, since the plants are not equipped for separating the good rock from the clay matrix.

The breccia and stony varieties of white phosphate have not heretofore been considered worth mining. Their low content of phosphoric acid is mainly due to the large quantity of silica or chert with which they are associated.

Hayes[2] suggests that the breccia variety might be utilized by crushing, and subsequently screening out the chert. It is possible that the stony variety could be handled in the same way. Another method of raising the grade of these two classes of white phosphate would be to grind the rock and then put it through a washing process similar to that employed in the brown-rock fields. It is very doubtful, however, if these varieties exist in sufficient quantities at any one place to justify the installation of expensive machinery.

EXTENT OF OPERATIONS.

Mining operations have been carried on in but two localities in the white-rock fields, namely, at the junction of Welsdorf Branch with Toms Creek, Perry County, about 5 miles east of the Tennessee River, and on Beech River, between Parsons and Decaturville, Decatur County, 6 to 8 miles west of the Tennessee River. The plants at these two places have not been operated for several years and will need considerable repairing before work can be renewed.

The total quantity of white phosphate marketed, according to Van Horn,[3] is about 8,600 tons. The annual output from 1905 to 1909 is given in Table IX.

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[1] Engineering Association of the South, Transactions, 15, 123 (1904).

[2] Mineral Resources, 4, Part IV, 625–626 (1894–95).

[3] Production of Phosphate Rock in 1909. Mineral Resources, U. S. Geological Survey.

PRESENT CONDITION OF THE INDUSTRY.

No work has been done in the white-rock fields since 1909. The uncertain character of the deposits, the expense of mining, and the inaccessibility of many of the deposits has discouraged both prospecting and development work. When the author visited these regions early in 1911 plans were under way to renew mining operations. The property of the Perry Phosphate Co. has been taken over by a new concern, a right of way has been secured to the Tennessee River, and several acres along the river front leased with a view to shipping the rock down this stream to Paducah, Ky.

Some New York capitalists are prospecting the property of the Beech River Phosphate Co. in Decatur County, and, if indications are favorable, expect to mine the phosphate on the west side of the Tennessee River.

FUTURE OPERATIONS.

Thorough prospecting is necessary to determine the value and extent of the white-rock phosphate deposits. Although several areas known to contain good rock are practically untouched, a systematic prospect of these will prove quite expensive. It is doubtful if the development of this class of rock will advance very rapidly as long as large, accessible, and more uniform beds of high-grade brown-rock and blue-rock phosphate remain available.

NATURAL PHOSPHATES OF KENTUCKY.

DESCRIPTION OF DEPOSITS.

Within the last few years considerable interest has been manifested in the phosphate deposits of Kentucky, but conflicting rumors concerning the value of these fields have confused the prospective investor and discouraged mining development. Mention was first made of the phosphatic nature of certain strata in Kentucky by Robert Peter[1] in 1877. This author described a thin layer of highly phosphatic limestone occurring in the "Lower Silurian" (Ordovician) near Lexington. These layers were regarded as of too irregular distribution among the poorer limestones to be of any great commercial value.

LOCATION OF DEPOSITS.

No importance was attached to these fields until the summer of 1905, when a negro formerly employed in the phosphate mines of Mount Pleasant, Tenn., discovered a deposit of similar nature while digging post holes on the farm of H. L. Martin, near Midway, Ky. He showed the material to Mr. Martin and Mr. A. W. Davis, both of whom were familiar with the Tennessee phosphate, and who recognized the value of the discovery. Since that time prospecting has been carried on intermittently at various points in Fayette, Woodford, Scott, and Jessamine counties, but no satisfactory and unbiased report on these deposits has as yet been published.

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[1] Kentucky Geological Survey; chemical analysis A, 1877.

Unfortunately, many of the prospect pits have been filled in and the natural exposures are few, although plans are under way for starting development work.

The phosphate area so far examined lies in Woodford, Fayette, Scott, and Jessamine counties, but the most thoroughly prospected properties lie in Woodford County, in the vicinity of the little town of Midway. Here a number of pits and prospect holes have been dug and deposits of considerable value discovered. The phosphate area is certainly of wider extent than is generally believed (fig. 2), and though the material obtained from some localities does not appear to be of much economic importance, more thorough examination will no doubt lead to the discovery of other valuable deposits.

In Table XIII are given the analyses of samples of Kentucky phosphate from various localities. It must be understood that these samples are selected and do not in any case represent the average of that locality.

TABLE XIII.—*Samples of high-grade Kentucky phosphate from various localities.*

No.	Location.	Description.	Analysis.	
			P_2O_5.	$Ca_3(PO_4)_2$.
			Per cent.	*Per cent.*
110	Farm of M. D. Steel, 2½ miles south of Midway, Ky.	Hard, brown plates	34.02	74.35
112	Cogar farm, ½ mile south of Midway, Ky	Thin, soft plates	33.75	73.74
115	Slack's farm, 3 miles northwest of Midway, Ky.	Hard, brown, heavy plates	37.10	81.08
118	Outside State University grounds, Lexington, Ky.	Thin, brown, brittle plates	26.13	57.10
125	Smith's farm, 2½ miles east of Georgetown, Ky.	Brown, medium hardness	27.14	59.43
128	Cut 6 miles south of Lexington, Jessamine County, Ky.	Thin, brown plates	34.10	74.52

GEOLOGICAL OCCURRENCE.

The Kentucky phosphate region forms part of the great Cincinnati anticline extending from Nashville, Tenn., in a northeasterly direction through Lexington, Ky., almost to Cincinnati. South of this city it divides into two broad domes, one culminating near Nashville and the other in Jessamine County, Ky. This latter is known as the Jessamine Dome.

Erosion has destroyed much of the domelike structure of this last section, and in cutting through the younger formations has caused numerous exposures of the underlying strata.

All the exposed rocks of these regions are of sedimentary origin. The arching of the strata probably took place very gradually and

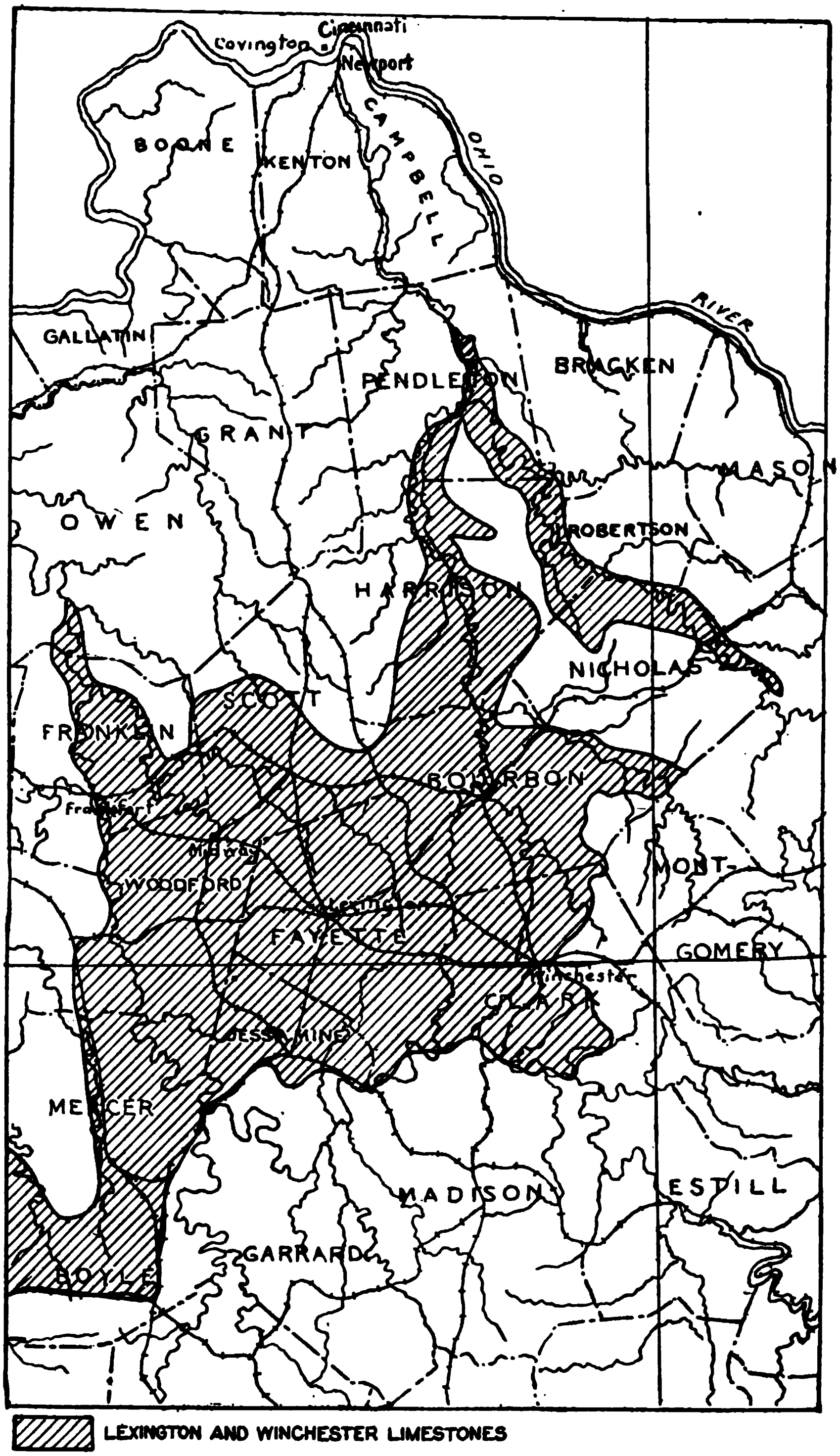

FIG. 2.—Map of the bluegrass region of Kentucky, showing distribution of the Lexington and Winchester limestones, between which phosphate occurs.

has altered the horizontal position of the rocks but little. The beds rarely dip more than a few feet to the mile.

The phosphate occurs in the Ordovician ("Lower Silurian") system, at the top of the geologic formation known as the Lexington limestone.

Table XIV, taken from the report of Matson[1] on the "Water Resources of the Bluegrass Region, Kentucky," shows the overlying and underlying formations which are more or less related to the phosphate beds.

TABLE XIV.—*Section showing phosphatic and related formations.*

System.	Formation.	Description.	Thickness.
			Feet.
Silurian and lower part of Devonian.	Panola	Blue shales and yellow limestone	60
Ordovician	Richmond	Heavy bedded, arenaceous limestone	60
		Blue limestone and shales	125
		Interbedded blue limestone and shales	80
	Maysville	Interbedded blue limestone and shales, thin and nodular; shales predominate.	230
	Eden shale	Shaly sandstones in southern part of region; blue shales in northern part.	200+
	Winchester limestone	Blue and gray limestone, with some blue shales	60
	Lexington limestone	Gray crystalline limestone, cherty (Flanagan chert member).	75
		[Phosphate Horizon.]	
		Argillaceous limestone and shale and bedded blue limestone.	194
		Heavy, bedded, coarse-grained crystalline, cherty limestone, usually gray.	30
	Highbridge limestone	Dense fine-grained gray limestone	90
		Dense fine-grained dove-colored or gray limestone.	20-60
		Dense, fine-grained, dark, heavy bedded limestone.	285
	....	Limestone known only from well records	100+
	St. Peters sandstone	Siliceous limestone	....

The phosphate rock occurs in thin plates embedded in a matrix of clay, siliceous material, and disintegrated phosphate, the whole having a thickness varying from a few inches to 10 or 12 feet. In some of the deposits considerable chert occurs, which may render the mining and grading of the phosphate somewhat difficult.

PHYSICAL PROPERTIES.

The phosphate rock itself varies somewhat in its physical properties. In color it ranges from a light gray to a rich chocolate brown and in texture from a compact, close-grained plate rock to porous cellular fragments and disintegrated phosphate.

Most of the rock is in thin, close-grained plates, brownish gray in color and fairly hard. The average apparent specific gravity is about 3.

Samples of the various types were analyzed, and the results of these analyses are given in Table XV, where the composition is compared with the predominant physical properties.

---

[1] Water Supply Paper, No. 233, United States Geological Survey. 1909.

Table XV.—*Composition of the different varieties of Kentucky phosphate.*

No.	Location.	Description.	SiO_2	$Fe_2O_3Al_2O_3$	P_2O_5	$Ca_3(PO_4)_2$
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
200 K	Near Midway, Ky.	Light yellow, brown, soft....	24.29	17.18	21.34	46.71
201 K	.....do.............	Brown, chocolate, close grained, thin bedded.	2.63	2.75	35.71	78.17
202 K	.....do.............	Brown, chocolate, porous, hard.	4.88	3.67	34.00	74.43

METHODS OF MINING.

Owing to the presence of so much finely divided foreign material in the phosphate deposits, it will be necessary to wash the phosphate rock before it can be used for the manufacture of acid phosphate. Plants for washing out the foreign material and at the same time saving the finely divided phosphate rock have proved very successful in the Tennessee phosphate fields. The method of separation is based on the difference between the specific gravities of the phosphate and the siliceous and clay matrix.

Where water is available both the overburden and phosphate might be successfully handled by the hydraulic method of mining. Since the deposits occur on the hills, the waste material could be disposed of by gravity. These methods entail considerable initial outlay, a fact that will probably militate against the small operator, as from an economic standpoint it is advisable that plants should be erected that will reduce the element of waste to a minimum.

In Table XVI the phosphate content of samples of the Kentucky phosphate before and after washing are given. The washing process, however, was not very thorough, as will be seen from the analysis.

Table XVI.—*Analysis of samples of Kentucky phosphate before and after washing.*

Sample number.	Location.	Depth.	Amount recovered after washing.	Analyses.					
				Before washing.			After washing.		
				SiO_2	Al_2O_3 Fe_2O_3	P_2O_5	SiO_2	Al_2O_3 Fe_2O_3	P_2O_5
		Ft. in.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
99-109	Shallow pit, filled, farm of M. D. Steel, 2½ miles from Midway, Ky...........	2	80.00	....	....	31.74	....	....	33.57
100-101	.....do..............	2 4	69.60	....	....	23.90	9.48	5.46	31.05
108-107	Deep pit on farm of M. D. Steel.........	3½	77.80	....	....	25.45	11.27	6.28	29.42
106-105	.....do..............	3 6	73.80	....	....	22.82	17.06	7.89	26.89
104-103-102	.....do..............	6 10½	76.00	....	....	22.85	11.96	7.55	29.23
[1] 113-114	Farm of J. Slack, 2 miles northwest of Midway, Ky.......	....	66.70	....	....	19.83	....	....	26.16
126-127	From cut 6 miles south of Lexington, in Jessamine County, Ky.......	8 3	36.36	....	....	23.70	16.01	12.34	29.29

[1] Contained considerable chert.

MARKETING.

As a distributing point for the Middle West, Kentucky is much better situated than Tennessee. During the year 1910 the sales of ground rock phosphate in those regions greatly increased, and though the average mine run of the Kentucky phosphate is probably not as high as that from the Tennessee brown-rock area, the difference in freight rates will compensate in many instances for the difference in the grade of the product.

Table XVII gives the freight rates from Midway, Ky., to towns in the middle West as compared with those from the phosphate regions of Tennessee.

TABLE XVII.—*Freight rates from mines in Kentucky and Tennessee to important near-by markets.*

Destination.	Location of mines.	Freight rates.
Cincinnati, Ohio	Midway, Ky	$1.57
	Mount Pleasant, Tenn	2.50
	Wales Station, Tenn	
	Nashville, Tenn	
Louisville, Ky	Midway, Ky	1.57
	Mount Pleasant, Tenn	2.00
	Wales Station, Tenn	
	Nashville, Tenn	
Cleveland, Ohio	Midway, Ky	3.72
	Mount Pleasant, Tenn	3.80
	Wales Station, Tenn	
	Nashville, Tenn	

PRESENT CONDITION OF THE INDUSTRY.

Up to the spring of 1911 work on the Kentucky phosphate area had been confined to prospecting. A small plant is now in course of construction which will start operations this year, and will probably accelerate greatly the development of the area.

The owners of phosphate lands are holding their property at high figures. This is partly due to the fact that shortly after the rock was discovered large sums were paid for options on several farms in the vicinity of Midway. These options were renewed upon payment of other large sums, but were finally allowed to lapse, owing to lack of capital to develop the properties. The farmers therefore have a somewhat exaggerated idea of the value of their farms.

Recently there were 2,400 acres under option or leased by companies and individuals interested in the phosphate industry. The land under lease is to be mined on the royalty basis, 25 cents to 50 cents being paid on every ton of rock produced, with a guaranty of a certain tonnage each year.

OUTLOOK.

It is only a question of time before the Kentucky phosphate fields will be developed. The value of the deposits has not as yet been sufficiently well established to encourage the outlay of much capital, but the erection of the plant cited above will draw attention to this area, and it seems probable that its favorable location and the character of the output will put mining operations in the area on a sound footing.

NATURAL PHOSPHATES OF ARKANSAS.

GENERAL DESCRIPTION OF DEPOSITS.

The phosphate deposits of Arkansas are not generally regarded as of great economic importance. Compared with the product of the Tennessee and Florida fields the rock is rather low grade. The deposits are well situated to supply the growing demand for fertilizers west of the Mississippi River, and, though much of the material is too low in phosphoric acid and too high in iron to make it desirable for the manufacture of superphosphate, the increasing consumption of ground rock phosphate for agricultural purposes will no doubt hasten further development in these fields.

The phosphate rock was not recognized as such until 1895, and it was not until 1896 that Branner[1] published a report on these deposits. In 1902 Branner and Newson[2] made a fuller geological report on these fields, embodying a large amount of analytical data and including a discussion of the transportation facilities and market for the product.

Purdue[3] published a short paper on the Arkansas phosphates in 1902, shortly after the plant of the Arkansas Fertilizer Co. was burned, but since that time, so far as can be learned, no publication of any note has been issued.

LOCATION OF DEPOSITS.

The portion of the phosphate fields now being worked lies in the northwestern part of Independence County, along Lafferty Creek, north and east of the White River. The deposits, however, extend over a considerable area in north-central Arkansas (fig. 3), and the phosphate horizon has been recognized in Stone, Izard, Searcy, Marion, Baxter, and Newton Counties.

Mention has also been made of the occurrence of phosphate nodules in Clark County at a different geological horizon, but the pebbles have never been found in sufficient quantities to prove of economic interest.

Some of the samples from other sources have analyzed very much higher than those from the deposits along Lafferty Creek, but transportation facilities are poor or, upon further investigation, the material has been found to be limited in quantity. This is the objection to the deposits found in Hickory Valley, where samples have been collected which ran over 73 per cent of $Ca_3(PO_4)_2$.

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[1] Amer. Inst. Min. Eng., 26, 1896.

[2] Bul. No. 74, Ark. Agr. Expt. Sta., 1902.

[3] Bul. 315, U. S. Geological Survey, 463-473 (1907).

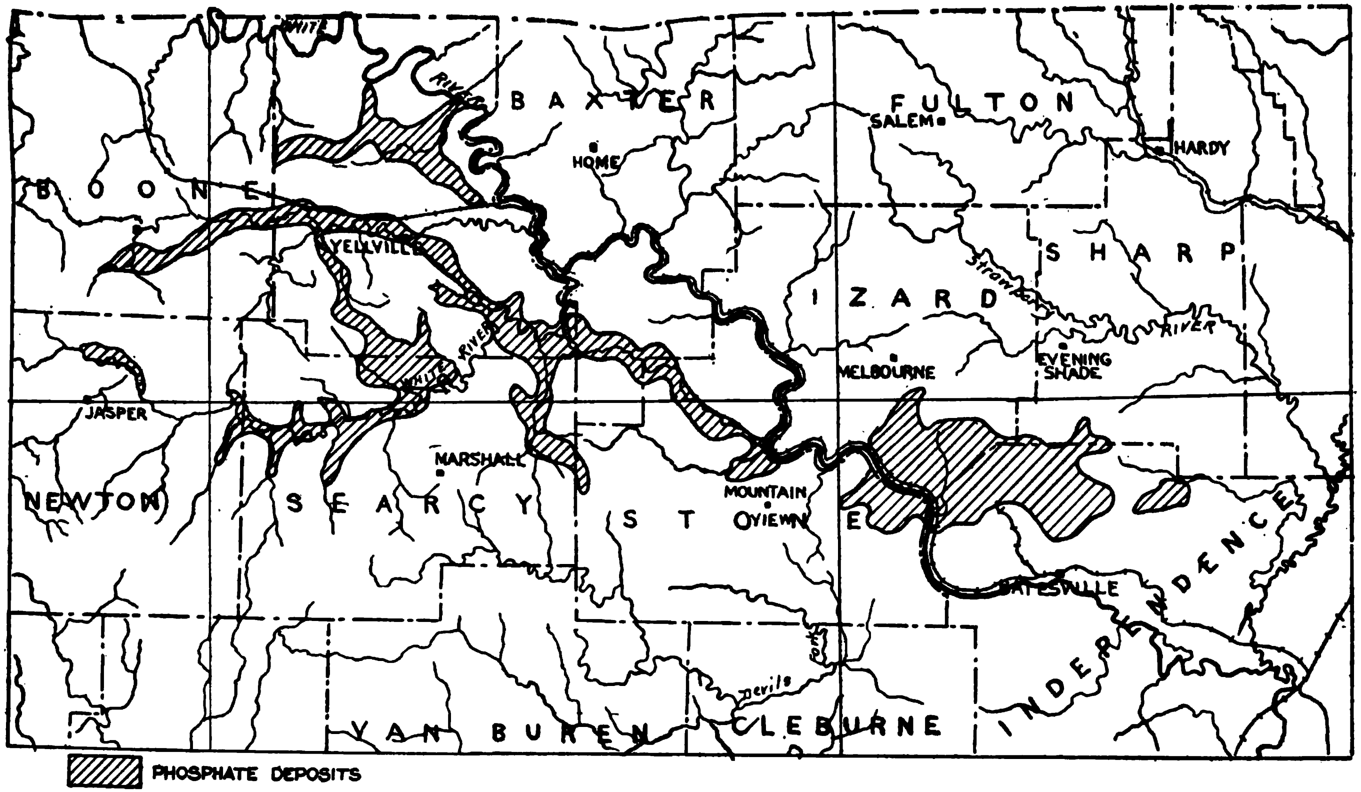

FIG. 3.—Map of northern Arkansas, showing location of reported phosphate deposits.

The analyses given in Table XVIII, taken from the report of Branner and Newson,[1] give some idea of the character and richness of the phosphate rock from other localities.

TABLE XVIII.—*Analyses of Arkansas phosphates.*

Location.	Thickness and character of beds.	Analysis.	
		$Ca_3(PO_4)_2$.	$Fe_2O_3Al_2O_3$.
		Per cent.	*Per cent.*
Milligan place, 12 miles northeast of Batesville (T. 14 N., R. 5 W., sec. 6).	5 feet	47.19	....
Do	Washed pebbles	73.76	3.82
Do	Not determined	57.03	5.89
Do	....do	64.17	3.08
Do	Bowlders	67.79	8.01
Do	Fragments	73.20	5.19
Do	Not determined	62.03	2.97
Meeker place, ½ mile west of Cushman (T. 14 N., R. 7 W., sec. 8).	2 feet 6 inches	49.38	8.82
Meeker place, ½ mile west of Cushman (T. 14 N., R. 8 W., sec. 12).	2 feet	58.31	5.85
Meeker place, ½ mile west of Cushman (T. 14 N., R. 8 W., sec. 14).	1 foot 6 inches	68.72	8.31
Tate's field (T. 14 N., R. 8 W., sec. 4)	1 foot	66.39	4.13
Keeling's place (T. 16 N., R. 16 W., sec. 18)	4 feet (reported)	76.62	7.21
Monkey Run, near St. Joe, Searcy County	Nodules (black)	69.31	8.10
Do	Nodules (brown)	56.58	9.01

GEOLOGICAL OCCURRENCE.

The exposed rocks in Northern Arkansas are all of sedimentary origin, the strata lying almost horizontally. The commercially important deposits of phosphate were formerly considered of Devonian age,[2] but more recent investigations have shown that they are older, but that they are not younger than the Silurian period.[3] The Cason shale, in which they occur, is of Ordovician age. The following summary, taken from the report of Purdue, shows a general section, with the formations more or less related to the phosphate beds:

Carboniferous	Boone chert, including St. Joe marble.
Devonian	Chattanooga shale and Sylamore sandstone.
Silurian	St. Clair limestone.
Ordovician	Cason shale (phosphate horizon). Polk Bayou limestone. Izard limestone.

As will be seen from inspection of the above table, the phosphate occurs between two limestone formations, both of which are characteristic and hence form excellent guides to the phosphate horizon. The overlying or St. Clair limestone in the vicinity of the developed phosphate deposits varies from 6 to 10 feet in thickness. It is a medium-grained, crystalline limestone, pinkish white in color, containing characteristic fossils, which stand out prominently on weathered surfaces.

The Polk Bayou limestone, the underlying formation, varies considerably in thickness, ranging from 75 to 130 feet. It occurs in

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[1] Bul. No. 74, Ark. Agr. Expt. Sta., 1902.

[2] Branner, Amer. Inst. of Min. Eng., 26, 1896; Branner and Newson, Bul. 74, Ark. Agr. Expt. Sta., 1903,

[3] Purdue, Bul. 315, U. S. Geological Survey, 463-473 (1907).

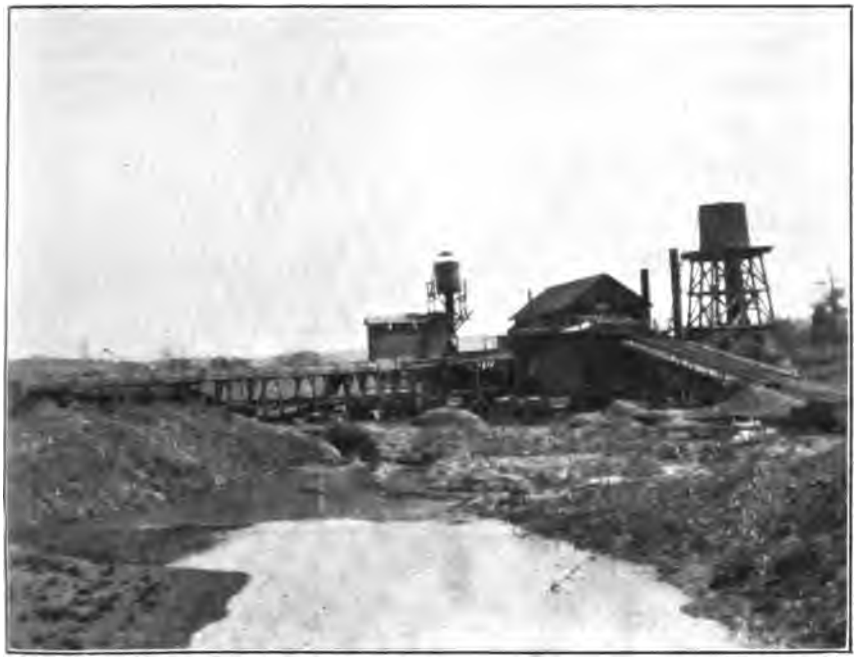

FIG. 1.—BROWN-ROCK PHOSPHATE PLANT, SHOWING WASTE POND IN FOREGROUND.

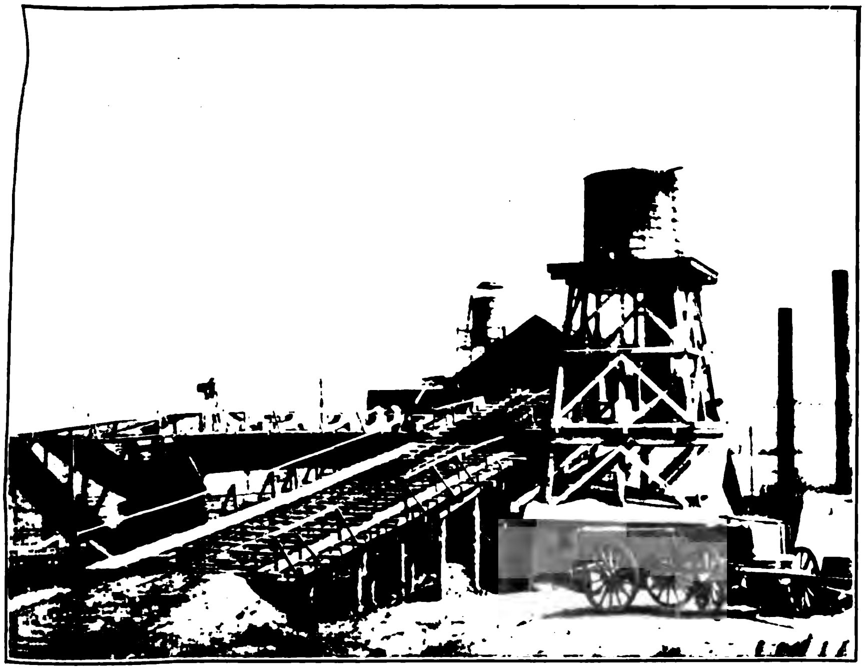

FIG. 2.—BROWN-ROCK PHOSPHATE PLANT, SHOWING HOOD OVER STACK AND SETTLING TANKS FOR FINELY DIVIDED PHOSPHATE.

BLUE ROCK MINE, TWO AND ONE-HALF MILES SOUTHEAST OF CENTERVILLE, HICKMAN COUNTY, TENN.

massive beds and varies in color from light gray to chocolate brown. Its texture is very coarse, the rock being made up of fossil fragments cemented together with crystals of calcite. This limestone rests directly upon the Izard limestone, which consists of a very close-grained limestone, almost fine enough to be used as lithographing stones. In some localities the Izard attains a considerable thickness.

The rocks of the phosphate horizon vary considerably in character, but there are always bands of shale occurring among the phosphate strata. Manganese ore is also closely associated with the phosphate in many places, much of the rock being stained by this substance. The finding of manganese ore has often led to the location of the phosphate.

Branner[1] states that the Arkansas phosphate is derived from the droppings and remains of fish and other marine agencies laid down gradually in deep water. Clark[2] is of the opinion that these deposits were formed in a similar manner to those of Tennessee, i. e., laid down in a shallow sea as phosphatic limestones and subsequently enriched by mechanical and chemical processes. Purdue[3] concludes, from the conglomerate character of the rock, that the deposition of the phosphate beds took place in shallow water, having closely followed the shore line as it advanced inland. The presence of large quantities of organic fragments indicate, in the opinion of this authority, that the deposits are the result of wave action.

Taking into consideration the close-grained character of the phosphate rock, it is unlikely that there has been any enrichment brought about by the leaching out of carbonate of lime subsequent to the final deposition of the phosphate strata.

The following sections (Table XIX), sampled at two different localities, show the nature and phosphoric-acid content of the various phosphate strata:

TABLE XIX.—*Analysis and description of phosphate strata from different localities.*

Sample No.	Location.	Thickness of strata.	Description.	Analyses.	
				P_2O_5.	$Ca_3(PO_4)_2$.
		Feet.		*Per cent.*	*Per cent.*
	"Phosphate," 12 miles northwest of Batesville.	2.5	Ferruginous limestone (roof)	Trace.	Trace.
93	.....do	.5	Green shale (weathered powder)	5.82	12.72
89	.....do	4.0	Hard, gray, nodular	28.85	63.05
91	.....do	2.0	Hard, gray, less nodular	14.16	30.94
97	1¾ miles north of Phosphate.	1.5	Ferruginous phosphate	19.60	42.94
	.....do	.5	Thin-bedded shale (not sampled)	....	....
96	.....do	3.0	Hard, gray oolitic phosphate	22.96	50.18
95	.....do	1.0	Hard, gray oolitic phosphate, low grade.	10.01	21.87
98	....	Undetermined	Ferruginous shale	7.53	16.45

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[1] Amer. Inst. Min. Eng., 26, 1896.

[2] Data of Geochemistry.

[3] Bul. 310, U. S. Geological Survey, 471–472 (1907).

PHYSICAL PROPERTIES.

The phosphate in the developed area occurs in two strata, one directly overlying the other. The first or upper layer is from 3½ to 6 feet in thickness and consists of a hard, massive rock made up of rounded fragments of organic débris closely cemented together. Its specific gravity is about 3. It varies in color from light gray to brownish-black, the color depending largely on the content of iron and manganese. This is the bed considered worth mining.

Directly under this bed lies another stratum of phosphate rock from 2 to 4 feet in thickness and closely resembling that just described. It is, however, less oolitic and contains appreciably less phosphoric acid. This stratum is discarded in mining.

Table XX gives the analyses of typical samples of Arkansas phosphate, together with the more prominent physical characteristics of the rock.

TABLE XX.—*Analysis of typical samples of Arkansas phosphate.*

No.	Location.	Thickness.	Description.	Analyses.		
				SiO_2.	Fe_2O_3-Al_2O_3	P_2O_5.
		Feet.		*Per cent.*	*Per cent.*	*Per cent.*
96	1½ miles north of Phosphate..	3	Hard, gray oolitic..........	39.94	7.00	22.96
95	.....do......................	1	Hard, brownish black, low grade.	58.25	2.43	10.01
92	"Phosphate." Arkansas Fertilizer Co., east side of creek.	6	Hard, grayish brown, oolitic high grade.	24.31	9.33	24.80
91	"Phosphate." West side of creek, Arkansas Fertilizer Co.	2	Hard, gray, low grade.......	24.94	7.43	14.16

METHODS OF MINING.

The Arkansas phosphate is mined in the same way as the blue-rock phosphate of Tennessee, by first stripping around the face of the hill till the overburden becomes too heavy to be profitably removed. Drifts are then run into the hillside and the rock blasted out. From the tunnel mouth it is loaded for shipment or piled upon ricks of wood and burned, the latter process being favored at the mines, as fuel is abundant and burning reduces freight charges by expelling most of the moisture from the rock.

It is claimed by the fertilizer manufacturer that burning the rock also facilitates crushing, since the ovules, which are usually the richest part of the phosphate rock, are rendered brittle and can be more finely ground for the subsequent acid treatment.

COST OF MINING.

The actual cost of mining varies considerably, depending on the accessibility and character of the deposit which is being worked. On the property of the Arkansas Fertilizer Co. most of the phosphate occurs some distance above the level of Lafferty Creek, but dips below this stream as one follows the stratum south. The extraction of material in the latter case will no doubt prove quite expensive.

Owing to the resistance of phosphate to weathering influences, the rock frequently forms a kind of bench around the hills, the overburden being largely removed by erosion for some distance back from the phosphate outcrop. Mining under these conditions can be carried on for some time by simply scraping off the light overburden or detritus and blasting or cutting out the rock thus exposed. This class of mining should be carried on at a cost not exceeding 75 cents per ton.

As the overburden gets heavier it becomes necessary to run drifts into the hillside and mine the material very much like a seam of coal. This latter method is more expensive than the open-cut systems, since much waste material has to be hauled out of the tunnels and considerable timber used in supporting the roof. As the tunneling proceeds farther into the hills less timbering is usually required, as the St. Clair limestone and unweathered slate overlying the phosphate form a fairly substantial roof. The average cost per ton is rather hard to strike, but, all things considered, it is probably less than $2.25.

MARKETING.

All the material mined on Lafferty Creek is at present shipped to Little Rock, Ark., and either made into acid phosphate or sold directly to farmers as ground rock phosphate. The acid phosphate contains about 14 per cent of phosphoric acid.

The freight rate on phosphate rock from Batesville to Little Rock, Ark., is $1 per ton.

OPERATING CONDITIONS.

The phosphate stratum directly underlying the main bed is either left untouched or taken out and discarded in mining operations. It varies from 1 to 4 feet in thickness and contains an average of 30 to 40 per cent of tricalcium phosphate, $Ca_3(PO_4)_2$. At present it would not be practicable to ship this material, since the freight rate is too high and the material of too low grade for the direct manufacture of acid phosphate.

Ground rock phosphate has not been used to any extent west of the Mississippi River, the present demand being for 62 per cent rock. This lower-grade phosphate would prove of value when ground, but the application would have to be heavy, and unless the market was within easy reach of the mines it would not be possible to dispose of the material at a profit. If the present tunnels are not allowed to collapse it will be possible to return and mine the low-grade rock when the market and improved methods of handling it shall make it profitable.

Only one company has mined Arkansas phosphate to any extent. In sec. 14, T. 14, R. 8 W, 12 miles northwest of Batesville, near the junction of East and West Lafferty Creeks, the phosphate has been opened up by 9 tunnels run into the hill on the west side of the creek. Numerous rooms branch out from these main tunnels, and fully 50,000 tons of rock have been taken out. The stratum of high-grade phosphate here has an average thickness of 3½ to 4 feet.

As the phosphate is traced southward on the west side of the creek the beds dip rather sharply, and when the mines were visited in May, 1911, a shaft was being sunk below the level of the creek in order to locate the deposit.

On the east side of the creek the beds are nearly horizontal and considerably thicker, a 6-foot stratum being in evidence for one-half mile along the hillside. An analysis of an average sample of this stratum is given in Table XX.

OUTLOOK.

There is every probability that the mining operations in the Arkansas phosphate fields will be extended. A fertilizer company of Little Rock, Ark., is preparing to enlarge an already extensive plant and is contemplating the erection of a sulphuric-acid factory. A number of other companies and individuals have large interests in these fields, and although some of them were bought primarily to develop the manganese deposits, they will no doubt handle the phosphate rock as the demand for this material increases. The fact that manganese and phosphate are so closely associated in these regions is sufficient guaranty that the deposits will be extensively worked at some future date.

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Issued November 27, 1911.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 82.
MILTON WHITNEY, Chief.

THE EFFECT OF SOLUBLE SALTS ON THE PHYSICAL PROPERTIES OF SOILS.

BY

R. O. E. DAVIS,
Scientist in Physical Laboratory Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., June 23, 1911.

Sir: I have the honor to transmit herewith the manuscript of an article entitled "The Effect of Soluble Salts on the Physical Properties of Soils," by R. O. E. Davis, of this bureau. I would recommend that this article be published as Bulletin No. 82 of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

Recent investigations in soil phenomena as related to crop production have brought a recognition that all the factors, natural and artificial, which in their combined effect determine the amount and quality of crop, are mutually interdependent. Fertilizers have been shown to influence not only the chemical, but also the physical and biological properties of the soil in ways which find marked responses in the production of crops. It has also been shown that practically all the physical properties of a soil which are susceptible to control or management are directly dependent upon the moisture content. It is of prime importance, therefore, to determine what manner and what magnitude of effect do soluble salts of the types found in commercial fertilizers produce in the soil-moisture relations, and this problem has been met by Dr. Davis as shown in the following bulletin. It was not sought to determine specific results on particular soils. But, as Dr. Davis has amply demonstrated, soluble salts do produce physical changes in the soil which are of large magnitude, which can be observed and measured, and which have as important an influence on crop growth as do any other factors. While contributing to the evidence of the complexity of the phenomena of crop production, this investigation is nevertheless constructive in showing the nature of the problems and direction for detailed quantitative studies in particular cases. This investigation marks a distinct step forward in soil studies, in giving direct experimental proof for the conclusion from a priori reasoning that the physical effects of fertilizers are of as much importance as any others and can no longer be ignored in rational systems of soil management.

FRANK K. CAMERON,
In charge, Physical and Chemical Investigations.

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THE EFFECT OF SOLUBLE SALTS ON THE PHYSICAL PROPERTIES OF SOILS.

INTRODUCTION.

In a previous publication [1] of this bureau it was pointed out that the "physical condition of the soil is one of the most important factors in determining the crop adaptation and growth, and that the physical condition is largely dependent upon the moisture content of the soil."

Following the suggestion here brought out, it was thought advisable to study the effect of soluble salts in small quantities upon the physical condition of soils. Since the physical condition is dependent on the moisture content, whatever influences the moisture content will influence the physical condition, and the movement of moisture in the soil.

The majority of the experiments performed were in determining the apparent specific volume of soils to which various soluble salts had been added. This property was selected because it is probably most easily measured. Experiments on penetrability and the capillary movements of water were also carried out; and a few on the difference in vapor pressure of soil moisture caused by the addition of the salts. An effort was made by the use of microscope and lantern to distinguish a difference in the structure of an untreated soil and of a soil treated with soluble salts. These results are discussed in the bulletin.

The use of commercial fertilizers influences a great many of the factors [2] which control plant growth, and one of these factors is the physical condition. In this investigation the amounts of soluble salts used correspond to the amounts used in fertilizers. The effect of the salts is very marked, but, so far, they have not been correlated with any particular system of agricultural practice.

A number of investigators have noted in a general way that soluble salts exert an influence on the physical properties of the soil. Mosier [3] studied the peculiar characteristics of a certain soil and from his experiments concluded that "the only way by which we may change the physical composition (structure) of soils is by changing the amount of organic matter." The sample worked with contained a great deal of organic matter. After leaching with acid and ammonia, the soil would not granulate as well as before. The change was attributed to loss of organic matter. It might equally as well be attributed to the loss of soluble salts removed by the leaching. Wiley[1] says that soluble salts may have an effect on the water movement in the soil. Since there is a possible increase in the surface tension of soil water by the addition of salts, therefore the amount of water remaining in the soil is increased. This should probably be true of fertilizer salts, but soluble organic matter decreases the surface tension in general.

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[1] Bul. No. 50, Bureau of Soils, U. S. Dept. of Agriculture.

[2] Cameron, Jour. of Ind. and Eng. Chem., 3, 3, 188 (1911). J. Phys. Chem 14, 320 (1910).

[3] Cir. 82, Ill. Expt. Sta. (1904).

Wollny[2] has shown that hydrates of several salts affect the volume of a soil saturated with water containing them. Aikman[3] declares that the influence of farmyard manures can not be attributed alone to the amount of so-called plant foods which they contain, for these are not present in the proportions for crop requirement, and the form of nitrogen and phosphorus is not of the most valuable kind. He therefore concludes that the influence farmyard manure exerts on the *structure* of the soil is very great. Bovie[4] has noted that the addition of salts to a soil affected the amount of available moisture present in the soil. King,[5] in some field experiments noticed that manure apparently increased the upward capillary movement in the soil, and this was especially shown in dry weather. Watson[6] declares that the observations of King are due to the decreased rate of evaporation in a soil treated with manure rather than to increased capillarity. Den Berger[7] has performed some experiments on the change in volume of soils containing sodium chloride when the soil is saturated with water.

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[1] Agricultural Analysis, Vol. I, p. 170. Among the numerous references which might be cited, the following will show the status of this line of investigation: Wirkung kunstlichen Dunger auf die Durchlassigkeit des Bodens für Wasser. Edwin Blanck, Landw. Jahrb. **38**, 864 (1909); Über den Einfluss der kunstlichen Dungemittel auf der Verhalten des Wasser im Boden. Gross. Zeit. f. d. Landw. Verschwesen in Österreich, **4**, 80 (1903); Über die Prozesse der Bewegung des Wassers in der Salzlösungen im Boden. Krawkon, J. F. Landw., **48**, 209 (1900); Untersuch. über die Wasserkapazität des Boden. Ulrich, Forsch. a. d. Geb. der Agrik-Physik., **19**, 37 (1896); Beitrag zur Erforschung der Einwirkung der Salzdungung auf die physikalischen Bodeneigenschaften. E. Mitscherlich, Fühlings Landw. Zeitung, **51**, 580 (1902); also Bodenkunde f. Land. u. Forstwirte, p. 16 (1905); Untersuch. über die Wirkung der Kalidungen auf die Bodenfeuchtigkeit. F. Hollrung, Forsch a. d. Geb. d. Agrik.-Phys., **17**, 450 (1894); A. N. Pearson, Chem. News, **66**, 53 (1892); J. Beeson, Jour. Amer. Chem. Soc., **19**, 620 (1897); Der Einfluss des Kalkes auf die Wasserbewegung im Boden. Blanck, Landw. Jahrb. **38**, 715 (1905); **38**, 863 (1909); Über das Verhalten erdartiger Gemische gegen das Wasser. Adolf Meyer, Landw. Jahrb. **3**, 794 (1874); Untersuchungen über die wasserhaltende Kraft des Boden und Bodenbestandteile. Treutler, Landw. Vers.-Station, **14**, 301 (1871); Untersuchungen über d. Feuchtigkeitsverhältnisse des Bodenarten. Wollny, Forsch. auf d. Gebiete der Agrik-Physik, **20**, 482 (1898); Unterschungen über d. Wasserkapazität der Bodenarten. Wollny, Forsch. auf d. Gebiete d. Agrik-Physik 8, 3 (1886); Reynolds, Ontario Expt. Sta. Report, p. 2 (1892); Frear, Penn. Expt. Sta. Bull. 61 (1900); Theoretische Betrachtungen über die Beeinflussung einiger der sogen. physik. Bodeneigenschaften. Mittig. d. Landw. Inst. Breslau, **4**, 445; Über einiger phys.-chem. Vorgange bei der Einstehung der Ackererde. Rohland, Landw. Jahrb. **36**, 473 (1907). Der Einfluss von Kalk u. Humus auf die mech. u. phys. Beschaffenheit von Ton-, Lehm- u. Sandboden. W. Thaer, Jour. Landw., **59**, 6 (1911).

[2] Forsch. auf dem Agr.-Phys., **20**, 1 (1897).

[3] Manures and manuring, p. 273.

[4] Bul. Torrey Bot. Club, **37**, 290 (1910).

[5] Wis. Exp. Sta. Report (1892), p. 106; A. Muntz et H. Gaudechon, Ann. Sci. Agron. (3) **4**, II, 393–443 (1909).

[6] Iowa Acad. of Science Jour., **16**, 103 (1909).

[7] Dépt. Agr. Indes Néerl., Bul. 34 (1910).

All of the work here cited has the disadvantage that the effect is shown for some particular water content of soil, or else that the physical effect of salt is more or less a matter of conjecture. Cameron and Gallagher[1] have shown that the physical condition of the soil changes with the change in moisture content, and that there is a definite moisture content (optimum moisture content) at which a given soil is in the best physical condition. One of the objects of the present investigation was to determine if possible the effect of soluble salts upon the optimum water content. The soils used were a sand, clay loam, clay, and silt loam. After performing a number of experiments with the soils, the silt loam was found to be best adapted to the measurements, because it could be mixed with water and screened easily over a fairly large range of moisture contents.

PENETRATION.

METHOD OF EXPERIMENTATION.

The measurement of the cohesion of a soil has often been used as an indicator of the physical condition of the soil. Cameron and Gallagher[2] have shown that the cohesion is well measured by determining the penetration, which is a main factor in the ease of tillage. The method by which the resistance to the introduction into the soil of a pointed instrument is measured, as described by them, is the one employed in the present measurements. The soil in each case was screened by the method they adopted. The use of a mechanical shaker insures a more or less uniform packing of the soil, which it is impossible to accomplish by hand filling. Drawings of the apparatus are reproduced in figures 1 and 2. The screening apparatus consists

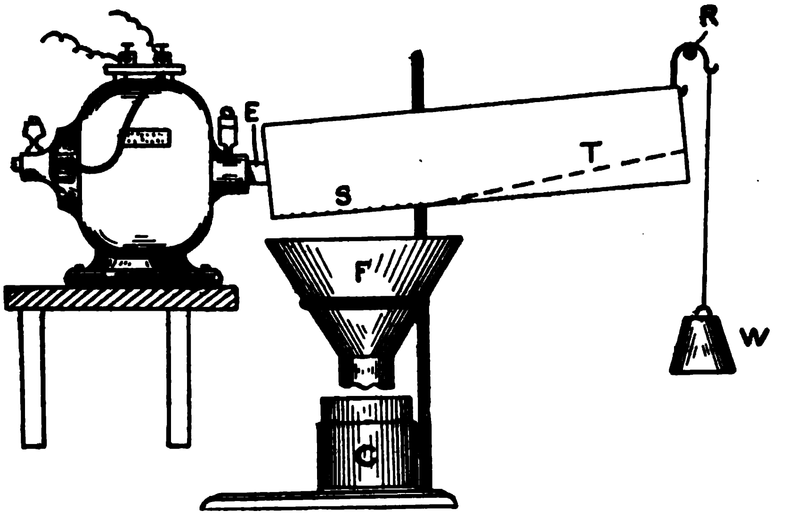

FIG. 1.—Apparatus for screening soils.

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[1] Bul. 50, Bureau of Soils, U. S. Dept. of Agr. (1908).

[2] Loc. cit.

principally of a screen operated by a motor. The screen is held in position at one end by a weight, the other end has a hole through which the eccentric shaft of the motor passes. A large funnel is used to catch the soil and divert it into the cup.

The penetration apparatus is a beam carrying a penetration tool at one end, counterbalanced by a weight at the other. When measurements are made, sand is run into the cup hung in the middle of the long arm of the beam, thus forcing the tool into the soil. The tool is a cone-shaped steel rod, 10.5 centimeters long and 1 centimeter at its greatest diameter. In the penetration measurements sand is run into the cup hung in the middle of the beam until the pointed instrument enters the soil just 6 centimeters. One-half the weight of sand added is the pressure applied at the end of the beam. The penetration measurements were made only on two soils and the method was then abandoned, because it was found that much more accurate results could be obtained by measuring the change in volume.

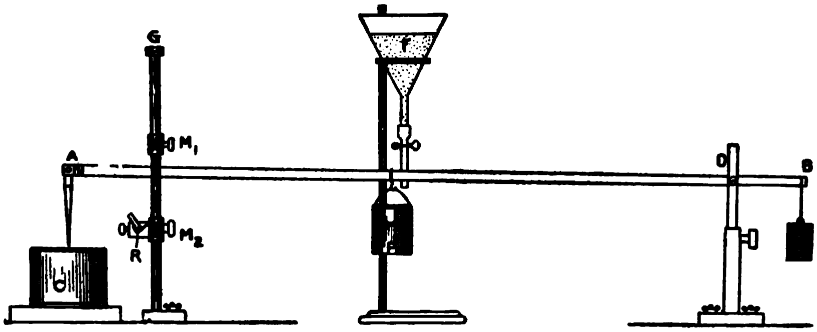

Fig. 2.—Apparatus for measuring penetration.

RESULTS OF EXPERIMENTS.

The two soils used for the experiments with penetration were the Cecil clay loam and Volusia silt loam. The mechanical analysis of the two soils are given in Table I.

Table I.—*Mechanical analysis of soils used in penetration experiments.*

Name of division.	Limits of sizes.	Cecil clay loam.	Volusia silt loam.
	Millimeters.	*Per cent.*	*Per cent.*
Fine gravel, coarse sand, and medium sand	2.0 -0.25	16	12.6
Fine and very fine sand	.25 - .05	25	16.7
Silt	.05 - .005	28	58.2
Clay	.005- .0	26	12.3

CECIL CLAY LOAM.

The clay loam is a rather heavy soil, and when containing more than 20 per cent water could not be screened. For that reason the curves with this soil do not extend beyond that moisture content.

From figures 3 and 4 the penetration curves for clay loam with water alone, three concentrations of potassium carbonate and two concentrations of potassium chloride are given. The results are shown in Tables II and III and figures 3 and 4. The dry salts were added to

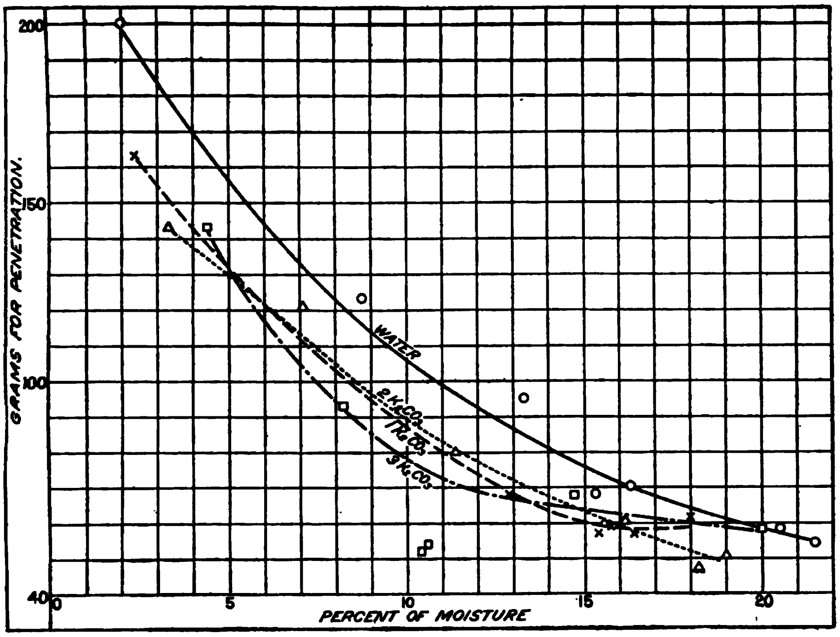

FIG. 3.—Penetration-moisture results for Cecil clay loam.

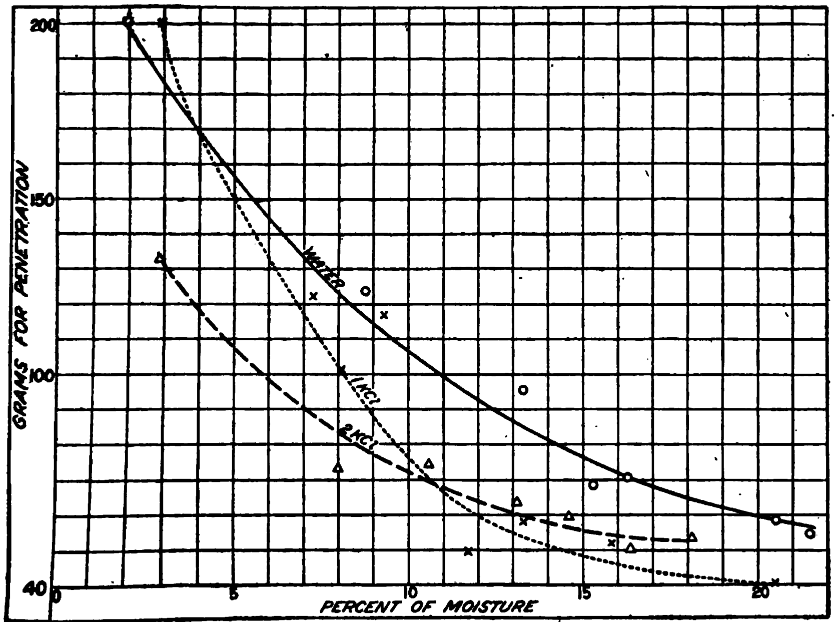

FIG. 4.—Penetration-moisture results for Cecil clay loam.

the soil and then the soil wet to saturation. After drying out, the soil was gradually mixed with water and at intervals the penetration measured. The amounts of carbonate were 4.5 grams to 1,500 of dry soil; 9 to 1,500, and 20 to 1,500. Chloride was added in the proportion of 5 and 15 grams to 1,500 of soil; or 0.3, 0.6, and 1.33 per cent for potassium carbonate and 0.33 and 1.0 per cent for chloride. It is noticed that the displacement of the penetration curve for soils with salt, from the curve with water alone is in the same direction in each case. The curves for penetration are not at all accurate. It is impossible to tell whether there is really a difference between the effect of different amounts of salts, because the error of experiment is so large. The only thing that can be said definitely is that the penetration value in the clay loam is lowered, since practically every measurement fell on the same side of the curve obtained for water alone. The amount of salt is considerably larger than the amount of fertilizer salts generally used.

TABLE II.—*Penetration-moisture relations for Cecil clay loam with potassium carbonate.*

With water alone.		0.3 per cent K_2CO_3.		0.6 per cent K_2CO_3.		1.33 per cent K_2CO_3.	
Moisture.	Weight for penetration.	Moisture.	Weight for penetration.	Moisture.	Weight for penetration.	Moisture.	Weight for penetration.
Per cent.	*Grams.*	*Per cent.*	*Grams.*	*Per cent.*	*Grams.*	*Per cent.*	*Grams.*
2.0	201.0	2.4	163	3.3	143	4.4	143
8.8	123.0	12.9	68	7.1	121	8.2	93
13.3	94.5	15.4	57	11.4	80	10.4	51
13.7	61.0	15.7	59	15.6	59	10.5	53
15.2	68.0	16.4	57	16.1	61	14.7	67
16.3	70.0	18.0	61	18.2	47	20.0	58
20.5	57.5			19.0	50		
21.5	53.5						

TABLE III.—*Penetration-moisture relations for Cecil clay loam with potassium chloride.*

0.33 per cent KCl.		1.0 per cent KCl.	
Moisture.	Weight for penetration.	Moisture.	Weight for penetration.
Per cent.	*Grams.*	*Per cent.*	*Grams.*
2.9	207	2.9	133
7.3	122	8.0	73
8.1	101	10.6	74
9.3	118	13.1	63
11.7	49	14.6	59
13.3	58	16.4	50
15.8	61	18.1	53
20.5	50		

VOLUSIA SILT LOAM.

Penetration measurements made on Volusia silt loam are shown in figure 5 and Table IV, for water alone and with potassium chloride, potassium carbonate, and phosphoric acid. Amounts of potassium chloride used were 0.09 gram and 9 grams to 1,500 grams of soil; or 0.006 and 0.6 per cent, and of potassium carbonate and phosphoric acid (P_2O_5) 1 gram to 1,500 of soil. The measurements are open to the same criticism as those for clay loam; but in this case the penetration value is apparently increased by the addition of these salts.

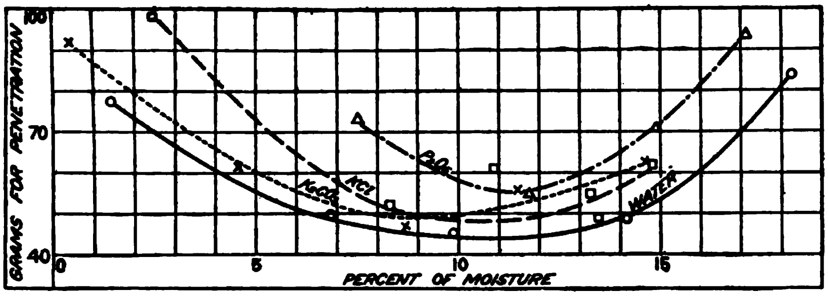

FIG. 5.—Penetration-moisture results for Volusia silt loam.

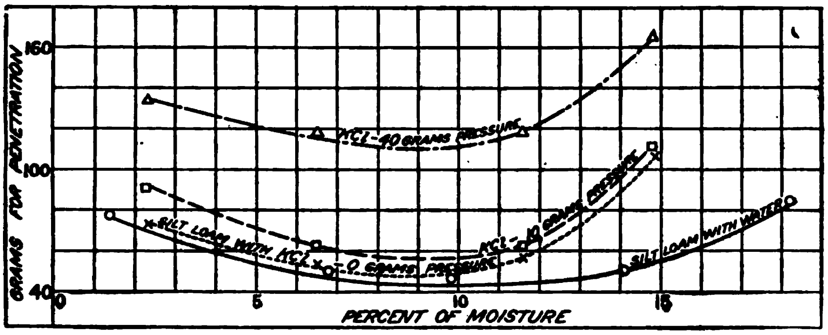

FIG. 6.—Penetration moisture results for Volusia silt loam.

In figure 6 and Table V are given values for the same soil and salts, except that the measurements are repeated after the soil has been subjected to a pressure of 10 and 40 grams per square centimeter surface. The curves are relatively the same as when no pressure is applied.

TABLE IV.—*Penetration-moisture relations for Volusia silt loam with salts.*

With water.		0.006 per cent KCl.		0.6 per cent KCl.		0.15 per cent K_2CO_3.		0.15 per cent P_2O_5.	
Moisture.	Weight for penetration.	Moisture.	Weight for penetration.	Moisture.	Weight for penetration.	Moisture.	Weight for penetration.	Moisture.	Weight for penetration.
P. ct.	*Grams.*	*P. ct.*	*Grams.*	*Per cent.*	*Grams.*	*Per cent.*	*Grams.*	*Per cent.*	*Grams.*
0.4	92	1.7	56	2.3	73	0.4	92	7.5	74
1.4	78	2.5	99	6.5	54	4.5	62	11.7	55
1.6	53	3.8	57	11.6	57	8.6	46	14.9	71
6.1	41	3.9	76	14.8	107	11.4	45	17.1	93
6.8	51	6.0	46			14.6	63		
8.0	35	8.2	46						
9.8	46	8.3	52						
12.3	59	8.3	55						
12.7	39	10.8	48						
14.1	50	10.9	61						
14.1	54	13.3	55						
15.7	64	13.5	50						
16.4	57	14.8	62						
18.2	82	15.4	62						
		17.0	101						

TABLE V.—*Penetration-moisture relations for Volusia silt loam, packed under different pressures and containing salts.*

Packing force per square centimeter.	With water.		0.006 per cent KCl.		0.6 per cent KCl.	
	Moisture content.	Weight for penetration.	Moisture content.	Weight for penetration.	Moisture content.	Weight for penetration.
0 gram	1.6	53	3.9	76	2.3	73
	6.1	41	8.3	55	6.5	54
	12.3	59	10.9	39	11.6	57
	16.4	57	15.4	62	14.8	107
10 grams	1.6	59	3.9	86	2.3	91
	6.1	57	8.3	64	6.5	63
	12.3	65	10.9	63	11.6	63
	16.4	85	15.4	77	14.8	111
40 grams	1.6	85	3.9	141	2.3	134
	6.1	136	8.3	157	6.5	118
	12.3	169	10.9	157	11.6	119
	16.4	229	15.4	223	14.8	165

ACCURACY OF PENETRATION MEASUREMENTS.

As has already been observed, the penetration measurements were not accurate; in fact, the error in the individual measurements was very large. Generally three measurements were made at points equidistant from the center of the cup containing the soil; and, in the first experiments, at the center also, but the center measurement differed so largely in every case from the others that it was discontinued. The time required for the sand to fill the cup (the rate of flow) caused a difference, as well as the height of fall, and the position the sand assumed in the cup. The sand was kept at as nearly constant head as possible, and a spring pinchcock was used so that the exit could be opened to full capacity and closed quickly and completely. Even then the measurements did not agree very well, the reason for the nonagreement probably being in the heterogeneous character of the soil and the impossibility of obtaining every portion of it in exactly the same condition. For instance, a small grain of sand immediately under the point of the penetration instrument might cause a difference of 10 to 20 grams in the penetrability of the soil. Several examples of measurements taken at random are given in Table VI as illustrative of the inherent errors of the method.

TABLE VI.—*Moisture-penetration measurements taken at random.*

Sample No. 1.		Sample No. 2.		Sample No. 3.[1]		Sample No. 4.[1]	
Time of adding sand.	Weight of sand.[2]	Time of adding sand.	Weight of sand.	Time of adding sand.	Weight of sand.	Time of adding sand.	Weight of sand.
Seconds.	*Grams.*	*Seconds.*	*Grams.*	*Seconds.*	*Grams.*	*Seconds.*	*Grams.*
26	149	15	129	38	193	40	154
28	152	15	136	60	278	40	227
24	137	17	135	62	281	40	209
23	147	15	127	35	190	30	160
23	135			38	196	30	170
25	138						
Error, per cent	12.6	Error, per cent	7.1				

[1] Tested as to the effect of time, the tool penetrating 6 cms.
[2] Actual weights of sand added; penetration value is one-half of this.

The results obtained in sample No. 2 are about as close as any obtained. In sample No. 4, in those cases requiring 40 seconds for penetration, the results vary from 154 to 227 grams. From these figures it may be seen that while the penetration method is of value in determining the general curve and the optimum water content for a soil, it can not be relied upon to detect small differences in the physical properties of a soil due to the addition of small amounts of soluble salts. Without a doubt, however, the measurements do indicate an effect upon the physical properties of the soil.

Having found that the soluble salts—potassium chloride and potassium carbonate—do affect the physical properties of the soil, but that measurements of penetration are not altogether satisfactory, it was determined to test the effect upon the apparent specific gravity. It was found that the measurements could be more quickly made and the results closely checked by duplicate measurements.

APPARENT SPECIFIC GRAVITY.

PREVIOUS WORK.

As previously noted, Çameron and Gallagher have shown that the apparent specific gravity $\left(\frac{\text{weight of soil}}{\text{volume occupied}}\right)$ is at a minimum at the optimum water content of the soil, but the effect of soluble salts was not studied. Wollny[1] made a few measurements on the increase in volume of kaolin by saturating with water and with solutions of several salts and hydroxides. The volume change was measured by a disk resting on the surface of the soil and supported by a weight attached by a cord passing over a pulley. A movement of the disk was indicated by an attached pointer moving over the face of a dial. The changes recorded are given in Table VII.

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[1] Forsch. auf dem Agr.-Phys., 20, 1-31 (1897).

TABLE VII.—*Measurements of increased volume of kaolin by saturating with various solutions.*

Soil with salt.	Change in volume.	Soil with salt.	Change in volume.
	Per cent.		*Per cent.*
H_2O	36.92	NaCl	19.32
K_2CO_3	27.67	$NaNO_3$	18.56
KOH	24.21	$Ca(OH)_2$	6.10

The changes given show that adding water to a dry soil until it is saturated causes it to increase in volume more than adding a solution of any of the substances tried. Calcium hydroxide caused the least change in volume, the increase being about one-sixth that caused by water alone. Den Berger[1] measured the effect of solutions of calcium chloride and sodium phosphate on the volume occupied by clay when settled from suspension. He found that the volume of soil (clay) with N/10 calcium chloride and N/200 calcium chloride is less than when wet with water alone. This was not true with sodium phosphate. Only two measurements were made in each case, and the differences recorded were very slight. Thaer[2] found that lime added to loams made them more porous to the passage of water, but added to sand, made them more compact.

METHOD OF EXPERIMENTATION.

The method used to determine the apparent specific volume of a soil was that of weighing full of soil a vessel whose volume was known. The screening apparatus already referred to was used. At first a large cup of 1,100 c. c. capacity was used, but was later discarded for one of about one-third the volume, when it was found that results just as accurate could be obtained with the smaller cup. The soil was allowed to fall from the screen until it overran the edges of the cup, and was then carefully leveled to the top of the cup with the edge of a large spatula. After weighing the cup and soil, the top of the soil was taken off and a representative sample from the interior of the mass placed in a weighing bottle and moisture determined. The per cent of moisture was in every case based on the dry weight of the soil. The soils used were the clay loams and silt loams used in the penetration experiments, Norfolk sand, and (in a few experiments) Susquehanna clay.

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[1] Bul. 34, Dept. Agr. Indes. Nĕerland (1910).

[2] Einfluss von Kalk u. Humus auf dem Ton-, Lehm- u. Sandboden. Thaer, Göttengen (1910).

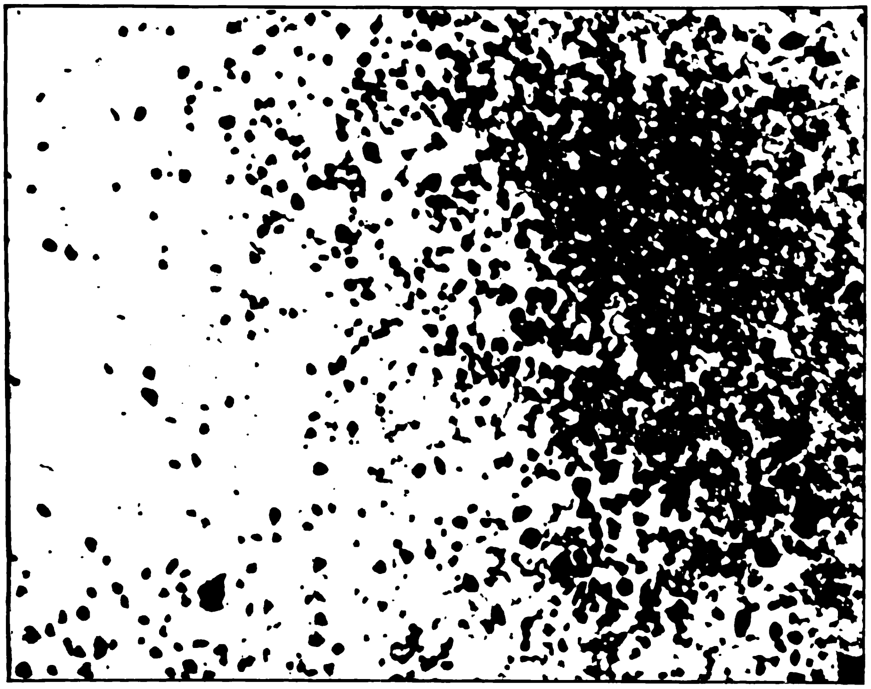

FIG. 1.—SAND MOISTENED WITH WATER.

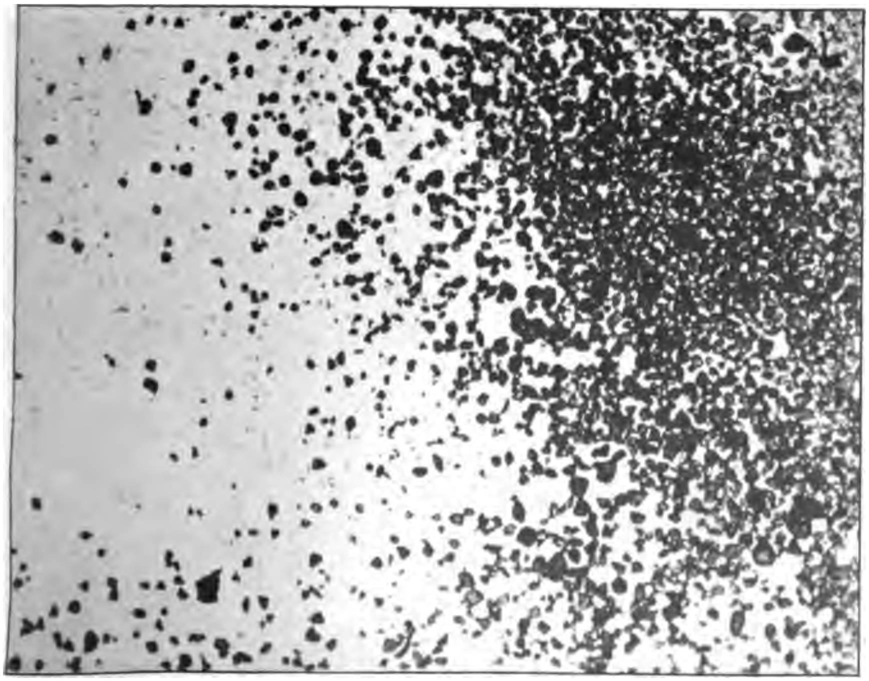

FIG. 2.—SAND AFTER THE EVAPORATION OF WATER.

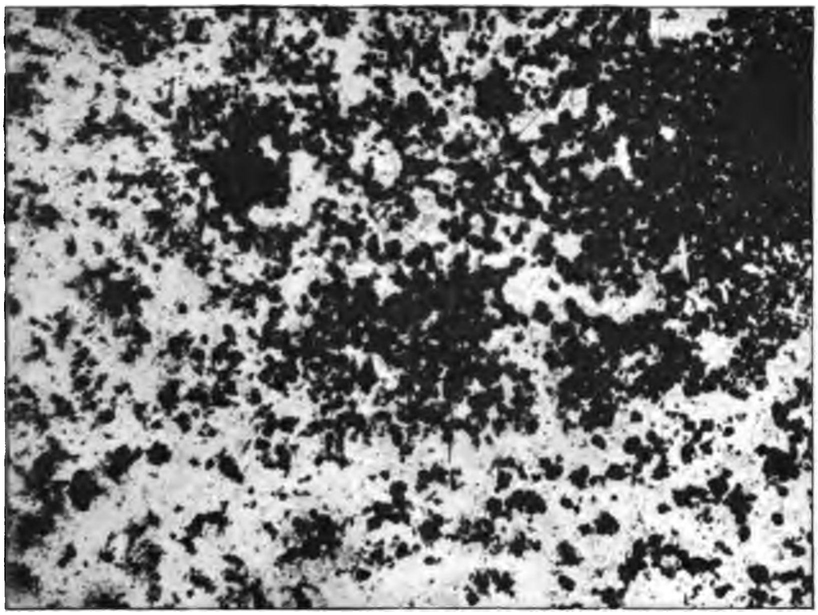

FIG. 1.—SAND WITH POTASSIUM CARBONATE MOISTENED WITH WATER.

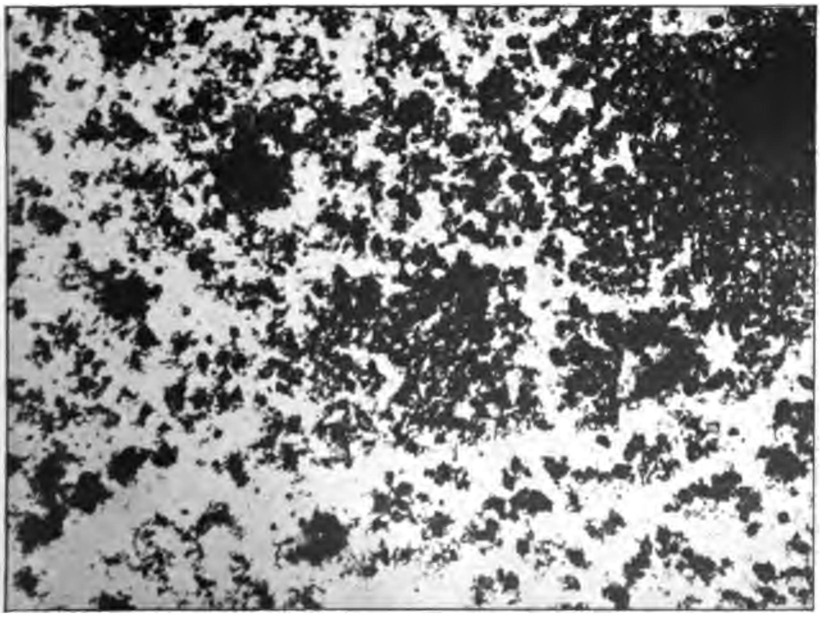

FIG. 2.—SAND WITH POTASSIUM CARBONATE AFTER EVAPORATION OF WATER.

RESULTS OF EXPERIMENTS.

CECIL CLAY LOAM.

The experimental results on volume-moisture relations with clay loam and each of the salts used in the penetration experiments are shown in Tables VIII and IX and graphically in figures 7 and 8.

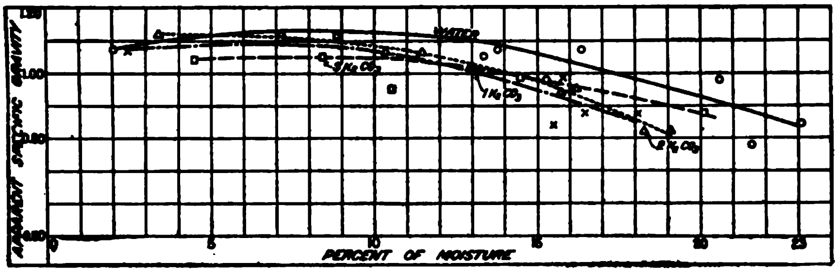

FIG. 7.—Moisture-apparent specific gravity results for Cecil clay loam.

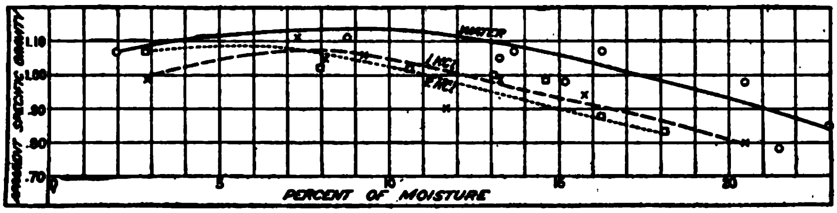

FIG. 8.—Moisture-apparent specific gravity results for Cecil clay loam.

TABLE VIII.—*Moisture-apparent specific gravity relations for Cecil clay loam and potassium carbonate.*

With water.		0.3 per cent K_2CO_3		0.6 per cent K_2CO_3		1.33 per cent K_2CO_3.	
Moisture.	**Apparent specific gravity.**	**Moisture.**	**Apparent specific gravity.**	**Moisture.**	**Apparent specific gravity.**	**Moisture.**	**Apparent specific gravity.**
Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
2.00	1.07	2.4	1.08	3.3	1.12	4.4	1.04
8.8	1.11	12.9	1.01	•7.1	1.12	8.2	1.05
13.3	1.05	15.4	.84	11.4	1.06	10.5	.95
13.7	1.07	15.7	.99	15.6	.98	14.7	.99
15.2	.98	16.4	.88	16.1	.95	20.0	.88
16.3	1.07	18.0	.88	18.2	.82		
20.5	.98			19.0	.82		
21.5	.78						

TABLE IX.—*Moisture-apparent specific gravity relations for Cecil clay loam and potassium chloride.*

0.33 per cent KCl.		1.0 per cent KCl.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*	
2.9	0.99	2.9	1.07
7.3	1.12	8.0	1.03
8.1	1.05	10.6	1.02
9.3	1.06	13.1	1.004
11.7	.90	14.6	.99
13.3	.99	16.4	.88
15.8	.94	18.1	.83
20.5	.80		

The results show that there is a very measurable effect produced in the volume-moisture relations of a soil by the addition of the soluble salts, potassium chloride and carbonate, that they both affect the volume change in the same direction, and there is apparently little difference produced by the different salts or by varying the concentration of the salts. The optimum water content was not quite reached.

VOLUSIA SILT LOAM.

With Volusia silt loam, experiments similar to those with Cecil clay loam were performed to note the effect of salts on the change in volume. In addition to potassium chloride and carbonate were used calcium sulphate, phosphoric acid, potassium bisulphate, monocalcium phosphate, ammonium nitrate, and several combinations of these salts. The results of these measurements are shown in Tables X, XI, XII, and XIII, and figures 9, 10, 11, 12, and 13. From the curves it is seen that the salts used are arranged in two groups. The single salts, potassium chloride, phosphoric acid, and potassium carbonate seem to cause the greatest displacement from that of the water alone, and the second group consists of potassium bisulphate, monocalcium phosphate, calcium sulphate, and ammonium nitrate. Mixtures of potassium chloride and ammonium nitrate and of calcium sulphate and potassium bisulphate fall in the first group; and of phosphoric acid and potassium carbonate or bisulphate fall in the second. Neither does concentration seem to have a very marked effect, as has already been shown in the case of the clay loam.

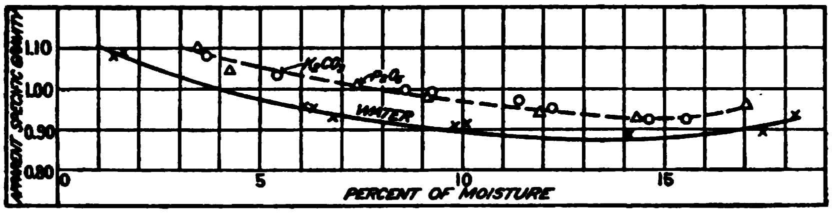

FIG. 9.—Moisture-apparent specific gravity results for Volusia silt loam.

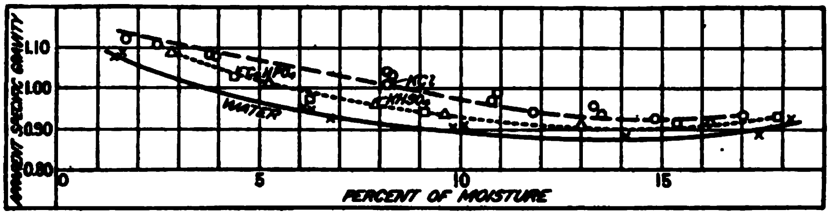

FIG. 10.—Moisture-apparent specific gravity results for Volusia silt loam.

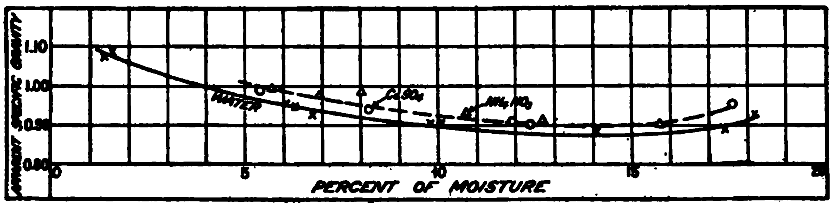

FIG. 11.—Moisture-apparent specific gravity results for Volusia silt loam.

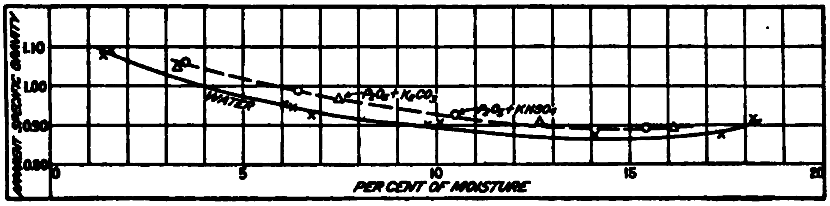

FIG. 12.—Moisture-apparent specific gravity results for Volusia silt loam.

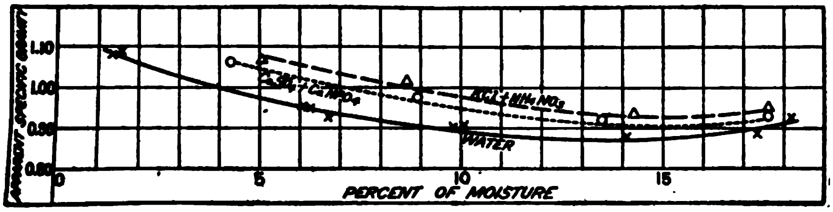

FIG. 13.—Moisture-apparent specific gravity results for Volusia silt loam.

TABLE X.—*Moisture-apparent specific gravity relations of Volusia silt loam with potassium chloride.*

With water.		0.006 per cent KCl.		0.6 per cent KCl.		1.2 per cent KCl.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
0.4	1.13	1.7	1.12	2.3	1.09	3.8	1.07
1.4	1.08	2.5	1.11	6.5	1.04	4.9	1.06
1.6	1.09	3.8	1.08	11.6	.95	6.4	1.07
3.9	1.08	6.0	1.06	14.8	.97	9.5	1.02
6.1	.96	8.2	1.01			11.1	.99
6.3	.95	8.3	1.05			12.7	.95
6.8	.93	10.8	.97			14.3	.97
8.0	.98	10.9	1.02			14.4	.93
8.3	1.04	11.8	.94			15.5	.98
9.8	.91	13.3	.97				
10.1	.92	13.5	.94				
12.7	.93	14.8	.93				
14.1	.89	17.0	.94				
14.1	.93						
15.4	.92						
15.7	.91						
17.4	.89						
18.2	.93						

TABLE XI.—*Moisture-apparent specific gravity relations of Volusia silt loam with salts.*

0.067 per cent K_2CO_3.		0.067 per cent P_2O_5.		0.133 per cent P_2O_5.		0.067 per cent $KHSO_4$.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
0.4	1.05	4.25	1.04	4.2	1.10	2.9	1.09
3.7	1.08	7.4	1.005	5.5	1.05	5.2	1.01
6.3	1.03	9.1	.97	8.2	1.04	7.9	.96
9.2	.99	11.9	.93	9.8	1.01	9.6	.94
12.2	.95	14.3	.92	12.5	.95	13.0	.91
15.4	.92	17.0	.96	16.1	.97	16.1	.93

TABLE XII.—*Moisture-apparent specific gravity relations of Volusia silt loam with salts.*

0.067 per cent $CaSO_4$.		0.067 per cent NH_4NO_3.		0.067 per cent $CaHPO_4$.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*		*Per cent.*	
5.4	0.99	5.7	0.99	4.3	1.03
8.2	.94	6.9	.98	6.2	.97
11.9	.91	8.0	.98	9.1	.94
12.4	.90	10.7	.93	17.9	.89
17.6	.95	12.7	.91		
		15.7	.90		
		17.8	.88		
		18.9	.89		

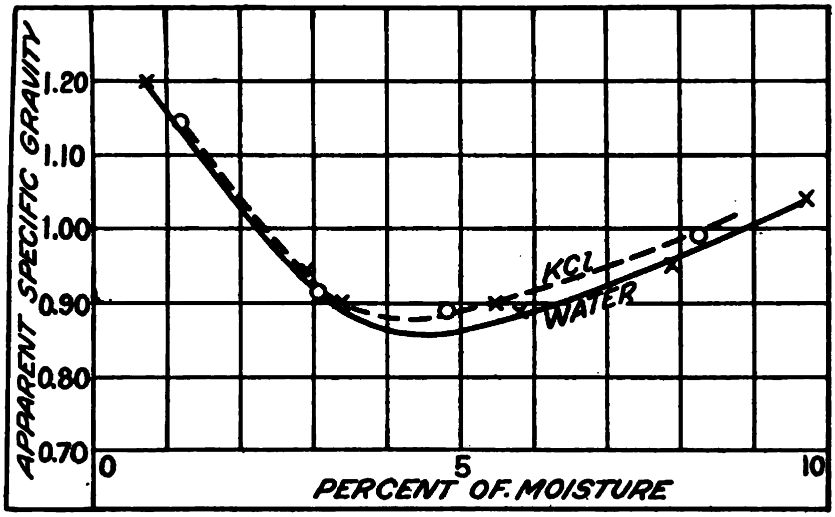

FIG. 14.—Moisture-apparent specific gravity results for Norfolk sand.

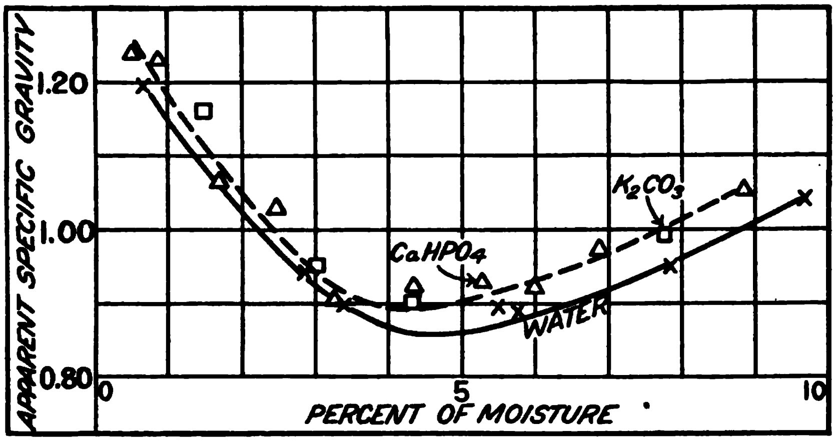

FIG. 15.—Moisture-apparent specific gravity results for Norfalk sand.

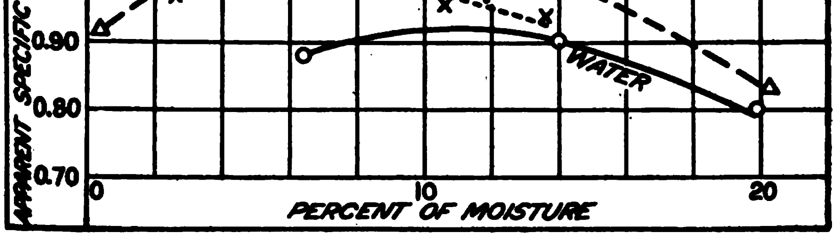

FIG. 16.—Moisture-apparent specific gravity results for Susquehanna clay.

TABLE XIII.—*Moisture-apparent specific gravity relations of Volusia silt loam with salts.*

0.016 per cent P_2O_5 and K_2CO_3 each.		0.032 per cent P_2O_5 and $KHSO_4$ each.		0.032 per cent KCl and NH_4NO_3 each.		0.032 per cent $CaSO_4$ and $CaHPO_4$ each.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
3.3	1.05	3.5	1.06	5.0	1.06	4.3	1.06
7.5	.97	6.4	.99	8.6	1.01	8.9	.98
12.7	.92	10.5	.93	14.3	.93	13.5	.92
16.1	.90	15.4	.90	17.6	.95	17.6	.93

NORFOLK SAND.

The effect of salts on change in volume of Norfolk sand was tried with only three salts—potassium chloride, carbonate, and calcium phosphate. The same sort of effect was shown as in the case of the clay loam and silt loam, but the differences were smaller. It was not deemed necessary to follow it up with other salts. The results of the experiments are shown in Table XIV and figures 14 and 15.

TABLE XIV.—*Moisture—Apparent specific gravity relations for Norfolk sand with salts.*

With water.		0.055 per cent KCl.		0.055 per cent K_2CO_3.		0.055 per cent $CaHPO_4$.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*		*Per cent.*		*Per cent.*	
0.74	1.20	0.19	1.45	0.55	1.24	1.52	1.16
2.9	0.94	0.55	1.24	0.97	1.23	2.96	0.95
3.4	0.90	1.15	1.14	1.70	1.06	4.32	0.90
5.5	0.90	3.00	0.91	2.50	1.03	7.81	0.99
5.8	0.89	4.8	0.89	3.30	0.90		
7.9	0.95	8.2	0.99	4.40	0.92		
9.7	1.04			5.30	0.93		
				6.0	0.92		
				6.9	0.97		
				8.9	1.05		

The mechanical analysis of Norfolk sand is given in Table XV.

TABLE XV.—*Mechanical analysis of Norfolk sand.*

Name of division.	Limits of sizes.	Percentage.
	Mm.	
Fine gravel, coarse sand, and medium sand	2.0 -0.25	30
Fine and very fine sand	0.25 -0.05	54
Silt	0.05 -0.005	10
Clay	0.005- .0	5

The curve is much sharper and the minimum is more distinct than in the other soils. This is due to the fact that the sand becomes saturated much more quickly than a soil containing smaller particles.

The total volume change for a sand is not near so great as that for clay or clay loam, but is greater for a short range of moisture content. This sand is saturated at about 10 per cent, while that per cent of water for most clays does not represent even one-half the amount required for saturation.

SUSQUEHANNA CLAY.

A heavy Susquehanna clay was selected to test the moisture-volume relations with salts, because in such a soil the effect of salts should be very marked. The mechanical analysis of the soil is shown in Table XVI. Only two salts were tried and then the experiments were abandoned because the soil quickly became too heavy and sticky to screen. Instead of passing through the screens, the clay formed compact balls. The curves are given in Table XVII and figure 16.

TABLE XVI.—*Mechanical analysis of Susquehanna clay.*

Name of division.	Limit of sizes.	Percentage.
	Mm.	
Fine gravel, coarse and medium sand	2.0 -0.25	8
Fine and very fine sand	0.25 -0.05	20
Silt	0.05 -0.005	35
Clay	0.005- .0	34

Although the curves are over a relatively very short range of moisture for this soil, those for the soil with salt show a marked displacement from the one for soil and water alone.

TABLE XVII.—*Moisture-apparent specific gravity relations of Susquehanna clay with salts.*

With water.		0.066 per cent KCl.		0.066 per cent K_2CO_3.	
Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.	Moisture.	Apparent specific gravity.
Per cent.		*Per cent.*		*Per cent.*	
6.4	0.88	2.6	0.97	0.4	0.92
41.0	.90	6.2	1.02	5.35	1.04
19.9	.80	8.4	.99	12.9	1.02
		10.6	.96	20.2	.83
		13.4	.94		

CAPILLARY MOVEMENT OF WATER.

PREVIOUS WORK.

The foregoing experiments seem to establish definitely the fact that the volume changes and penetrability of a soil are affected by the addition of a small amount of soluble salt, but they do not indicate how the movement of moisture in the soil is effected. For this reason experiments on the capillary movements of water in the soil with various salts were carried out.

King [1] observed that a certain soil that had been treated with barnyard manure was more moist than the same soil that had not been so treated. The difference was especially marked in dry season, and the effect was shown down to 4 feet depth at least. He attributed the difference to an increased upward capillary movement of water, brought about by the application of manure. It is a well-known fact that acids, bases, and salts do affect the capillary rise in absorbent material, and on this basis a system of analysis has been evolved by Goppelsroeder.[2] With the capillary rise of water solutions of acids Shraup [3] has been especially interested, and found that there is considerable difference in the heights to which the same strength of different acids rise. Cameron and Bell [4] found that potassium chloride had an effect upon the rate at which a solution rose in strips of filter paper. Krawkow [5] published some results on the effect on rate upon capillary flow of water in soil columns, caused by the addition of soluble salts. He found that the solutions moved less rapidly than in pure water, which he ascribed as due possibly to increased viscosity of the liquid. Briggs [6] studied the effect of several salts upon the capillary rise in soils. He used only concentrated solutions and found that the rise in soil columns was not as great as with pure water, but a solution of sodium carbonate rose higher than water alone. This he accounted for as being due possibly to the saponification by the alkaline solution of the slightly greasy film over the surface of the soil grains. One would expect it from carbonates, borates, and phosphates. Watson [7] performed some experiments on an Iowa soil, studying the effect of manure and peat on its physical condition, using glass tubes filled with soil, held upright. The heights to which water would rise in the treated and the untreated soil were compared after 14 hours, 38 hours, and 4, 5, 8, and 11 days. One per cent of manure showed a slight increase, 2 per cent a slight decrease, while peat showed considerable increase. The results obtained are shown in Table XVIII. Watson assumes that it is the "coarse, insoluble part of the manure which has the physical effect, and the soluble part has little or no effect."

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[1] Wis. Expt. Sta. Report, [illegible], p. [illegible].

[2] Kapillaranalyse beruhend auf Kapillaritäts- und Adsorptionserscheinungen. F. Goppelsroeder. Separatabdruck aus Kolloid-Zeit. vom January [illegible] bis April [illegible].

[3] [illegible], [illegible], 753 (1910); J. Chem. Soc., [illegible], 251 (1910).

[4] Bul. 30, Bureau of Soils, U. S. Dept. of Agr., p. [illegible] (1905).

[5] Jour. [illegible], St. Petersburg, [illegible] (1900); Chem. Zent. [illegible] (1900).

[6] Bul. 19, Bureau of Soils, U. S. Dept. of Agr. (1902).

[7] Iowa Acad. of Sci., [illegible], 103 (1909).

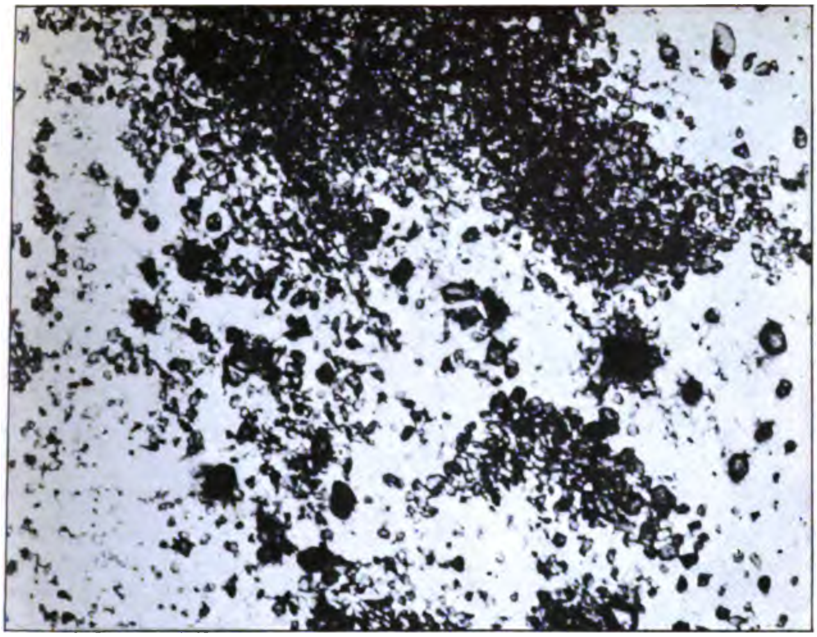

FIG. 1.—SAND WITH MONOCALCIUM PHOSPHATE MOISTENED WITH WATER.

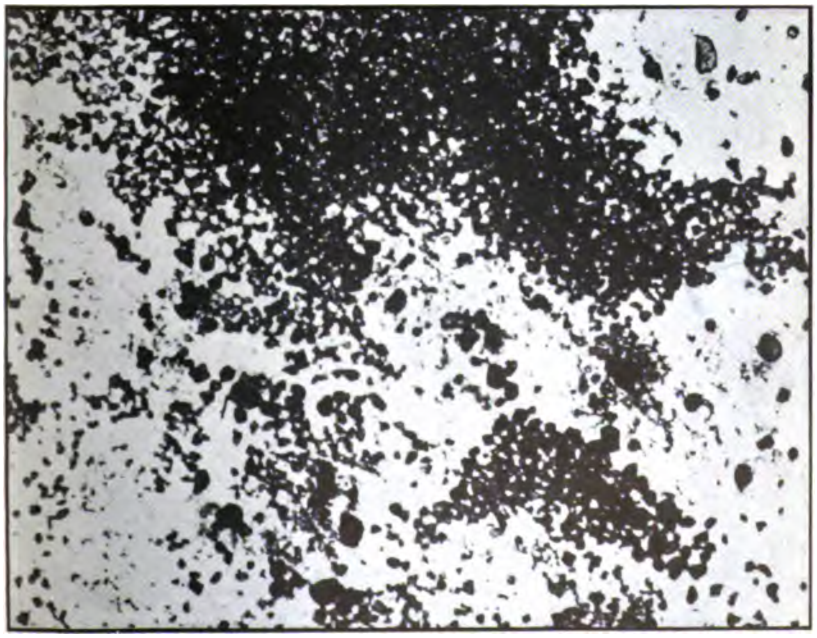

FIG. 2.—SAND WITH MONOCALCIUM PHOSPHATE AFTER EVAPORATION OF WATER.

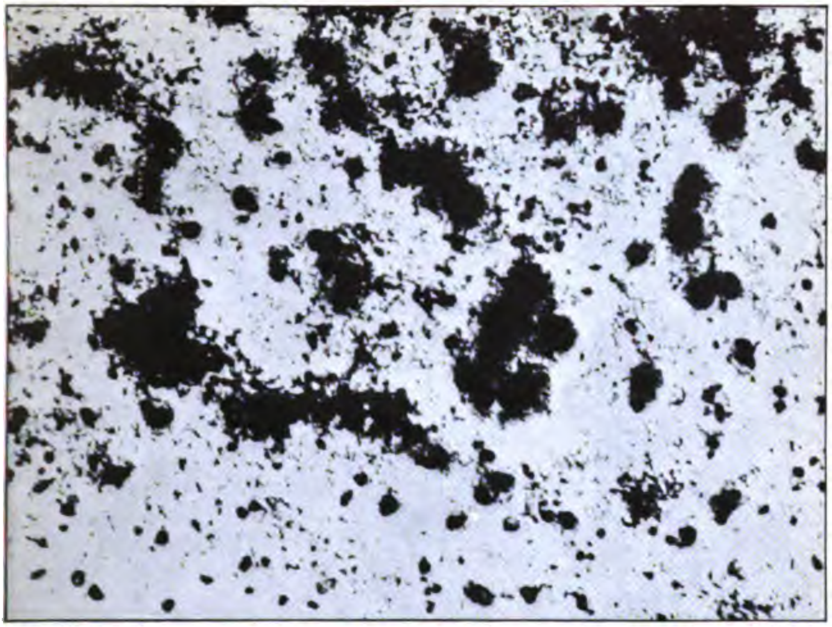

FIG. 1.—CLAY LOAM MOISTENED WITH WATER.

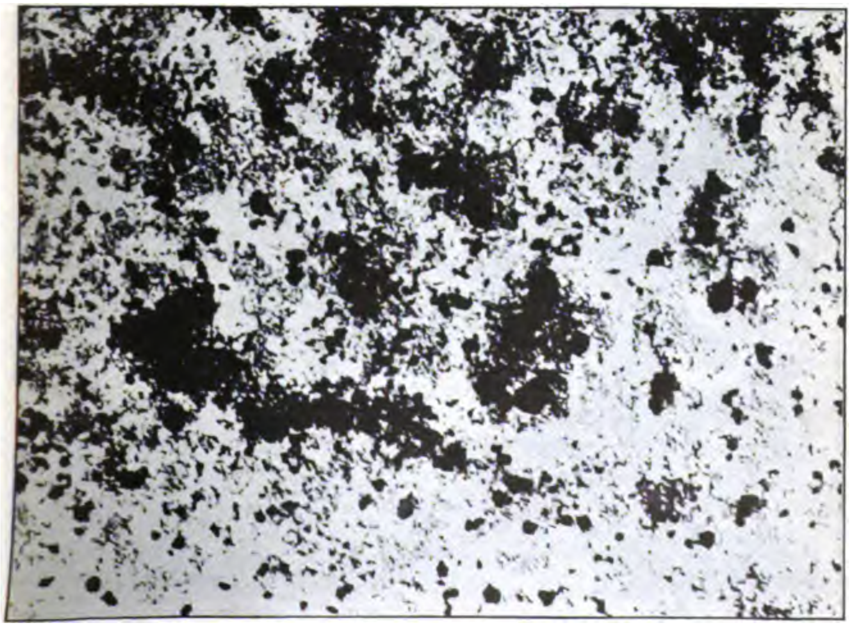

FIG. 2.—CLAY LOAM AFTER EVAPORATION OF WATER.

TABLE XVIII.—*Effect of manure and peat on capillary rise in Iowa soil.*

Soil.	Rise of water in centimeters after—				
	14 hours.	38 hours.	4 days.	8 days.	11 days.
Soil	11.2	14.5	17.7	20.5	22.1
Plus 1 per cent manure	12.0	15.2	18.2	20.7	22.3
Plus 2 per cent manure	11.0	13.5	16.7	18.0	20.0
Plus 1 per cent peat	14.2	18.5	23.0	24.5	26.1

METHOD OF EXPERIMENTATION.

The method followed in measuring the rate of capillary movement was to measure the movement of moisture along a horizontal tube filled with soil. The conventional method is to place the tube containing soil in an upright position in the water and then to measure the height above water level to which the water rises. The tubes used in these experiments were glass tubes *A*, figure 17, 1 inch in diameter, with a scale in millimeters pasted along their length. These tubes were connnected by strong rubber tubing to brass elbows *B*, the lower end of which dipped into water. The water supply was kept at constant level. In filling the tube the end was closed by a sheet of filter paper and the tubes filled to the same distance in each case and then tapped until the loose soil had subsided a determined number of centimeters (usually 5). The brass elbows were all filled with the same soil, rubbed up in a mortar with a rubber-tipped pestle, and as nearly as possible given the same packing in the tubes. The lower ends of the brass tubes were closed by perforated corks, with glass wool in the perforations and fine copper gauze over them. The ends were submerged in the water about 3 centimeters and allowed to stand there for 24 hours before the soil columns in the glass tubes were attached. In this way the soil in the brass elbows became saturated with water, and, on the assumption of uniform packing, furnished a constant head of water to each of the horizontal tubes. The movement of water was well defined, the moist soil giving in nearly every case a perfect ring at the point to which the moisture had advanced. The tubes were placed in a horizontal position to eliminate the effect of gravity. That this effect was measurable was shown by the first set of experiments, in which the tubes were placed in upright position. The influence of position upon the capillary movement was not studied, but that there is a measurable influence

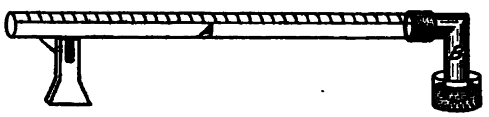

FIG. 17.—Tube used in experiments in capillary movement of water.

is shown by Goppelsroeder,[1] using filter paper and a solution of potassium sulphate. His results are shown in Table XIX. The effect of gravity is shown to increase the capillary flow with even so small a negative angle as 2° to the horizontal. Probably in the last two cases, with negative angles of 13° and 25°, there is a real flowing of liquid under the influence of gravity.

TABLE XIX.—*Influence of position on capillary rise of potassium sulphate solution in filter paper.*

Angle to horizontal.	Hours.	Height of rise.	Angle to horizontal.	Hours.	Height of rise.
°		*Cm.*	°		*Cm.*
90	65	46.3	− 2.0	65	130.3
53.9	65	57.5	−13.0	....	148.8
0	65	116.5	−25.0	....	200.0

RESULTS OF EXPERIMENTS.

The measurements in the present experiments were made on the silt loam soil used for measuring the change of volume and the same salts were added. The results of several sets of experiments are shown in Tables XX to XXII and in figures 18 to 20, inclusive.

The form of the curves are parabolic, in accord with the equation that represents the curve for capillary movements in porous material found to hold by Bell and Cameron,[2] namely, $y^n = Kt$, in which y is the height, t the time, and n and K are constants, depending on the temperature and the specific substances.

Curves in figures 18, 19, and 20 for only three of the five sets of experiments are given, as the others are similar in character. Tables XX to XXII give the results of the five sets. After each experiment the tubes were emptied and refilled with some of the same soil sample for the next experiment. The brass tubes connected to the soil columns were emptied and refilled between each set of experiments. With every precaution to make the soil columns uniform in texture and packing no two sets of experiments could be made to agree throughout. There is a general agreement, however. Take, for example, the first two sets of experiments. There is an agreement in the order of the curves with the exception of those for potassium chloride and for phosphoric acid and potassium carbonate.

In Table XXIII the total of all the experiments has been tabulated, at the end of 24 hours and at 48 hours. The fourth series did not extend beyond 24 hours, so that it is not included in the 48-hour totals. The fact that absolutely concordant results are not obtained seems to be due to the large error in filling the tube. In each case the tubes were placed in a vertical position and the soil allowed to flow in through a funnel held rigidly so that the distance the soil fell was the same for each tube. The tubes were all filled to 35 cms. and then tapped on the table until the soil level sank to 30 cms. If any irregularities in the texture of the soil column were visible, the tube was refilled. The difficulty of uniformly reproducing the same conditions in filling tubes has been observed by Den Berger,[1] who found that differences due to non-uniformity sometimes resulted in very large errors. Granting, however, that the error of filling or packing is large, it can hardly be doubted from the results of these experiments that the presence of the salts does exert an influence on the capillary movement of water in the soil. Not only the total but the individual experiments show that potassium bisulphate and a mixture of phosphoric acid with potassium bisulphate do lower the rate of capillary flow, that phosphoric acid and potassium chloride influence it very little, and that the other salts and mixtures accelerate the movement.

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[1] Loc. cit., Kapillaranalyse, p. 28.

[2] Jour. Phys. Chem., 10, 658 (1906); Bul. 30, Bureau of Soils, U. S. Dept. of Agr. (1905), p. 50; also Wo. Ostwald, Supplementheft 2, Zeit. Koll. Chem., 20 (1908).

TABLE XX.—*Capillary movement of water in silt loam containing salts.*

FIRST SERIES.

H_2O		K_2CO_3		KCl		P_2O_5		$KHSO_4$		$CaSO_4$	
Time.	Distance.	Time.	Distance.	Time.	Distance.	Time.	Distance.	Time.	Distance.	Time.	Distance.
H. m.	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*
32	1.0	25	1.0	25	1.0	35	1.0	38	1.0	25	1.0
1 14	2.0	1 11	2.0	2 20	2.0	1 40	2.0	2 26	2.0	1 11	2.0
2 43	3.0	2 26	3.0	5 30	3.0	5 46	4.0	4 40	3.0	2 51	3.0
4 40	4.0	4 01	4.0	24 00	7.6	24 00	9.1	7 30	4.0	4 59	4.0
7 30	5.0	5 18	5.0	48 00	12.6	48 00	14.5	24 00	7.5	7 20	5.0
24 00	8.4	7 00	6.0	51 00	13.0	51 00	15.0	48 00	12.5	24 00	10.0
48 00	13.0	24 00	11.9	54 00	13.8	54 00	15.6	51 00	13.0	48 00	15.5
51 00	13.5	48 00	19.0	72 00	16.8	72 00	18.7	54 00	13.3	51 00	16.0
54 00	14.2	51 00	19.6					72 00	16.3	54 00	16.8
72 00	17.1	54 00	20.4							72 00	19.9
		72 00	24.3								

KCl and NH_4NO_3		P_2O_5 and K_2CO_3		P_2O_5 and $KHSO_4$		$CaSO_4$ and $CaHPO_4$		$CaHPO_4$		NH_4NO_3	
Time.	Distance.	Time.	Distance.	Time.	Distance.	Time.	Distance.	Time.	Distance.	Time.	Distance.
H. m.	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*	*H. m.*	*Cm.*
25	1.0	17	1.0	10	1.0	15	1.0	25	2.0	12	1.0
1 11	2.0	51	2.0	50	2.0	51	2.0	1 45	3.0	49	2.0
2 26	3.0	2 00	3.0	2 51	3.0	1 45	3.0	5 30	5.0	1 45	3.0
4 50	5.0	4 40	5.0	6 45	4.0	4 26	5.0	24 00	11.0	2 43	4.0
6 45	6.0	6 20	6.0	24 00	6.6	6 05	6.0	48 00	17.0	4 17	5.0
24 00	12.8	24 00	12.5	48 00	10.0	24 00	12.1	51 00	17.5	5 30	6.0
48 00	20.5	48 00	19.6	51 00	10.5	48 00	19.0	54 00	18.2	7 20	7.0
51 00	21.3	51 00	20.2	54 00	10.9	51 00	19.7	72 00	22.2	24 00	13.1
54 00	22.2	54 00	21.1	72 00	13.0	54 00	20.5			48 00	20.5
72 00	26.5	72 00	25.2			72 00	24.3			51 00	21.3
										54 00	22.1
										72 00	26.4

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[1] Bul. 34, Dépt. Agr. Indes Néerland (1910).

TABLE XXI.—*Capillary movement of water in silt loam containing salts.*

SECOND SERIES.

[Distance in centimeters.]

Time.	H_2O	K_2CO_3.	KCl.	P_2O_5.	$KHSO_4$.	$CaSO_4$.	KCl and NH_4NO_3.	P_2O_5 and K_2CO_3.	P_2O_5 and $KHSO_4$.	$CaSO_4$ and $CaHPO_4$.	$CaHPO_4$.	NH_4NO_3.
H. M.												
30	....	1.2	1.1	....	....	....	....	....	....	1.2	....	1.2
38	1.0	....	....	1.0	....	1.0	1.0	....	....	....	....	....
42	....	....	....	....	....	....	....	....	....	....	1.0	....
45	....	....	....	....	1.0	....	....	....	....	....	....	....
50	....	....	....	....	....	....	....	1.0	1.0	....	....	....
2 00	1.8	2.2	2.0	2.0	1.6	2.1	2.4	1.5	1.4	2.3	2.0	2.4
4 00	2.4	3.2	2.7	2.8	2.2	3.0	3.7	2.3	1.8	3.5	3.0	3.8
7 00	3.0	4.5	3.5	3.6	2.9	4.0	5.3	3.1	2.4	5.0	4.1	5.4
24 00	5.8	9.8	7.2	7.2	5.6	8.4	11.6	6.5	4.7	11.2	8.9	12.0
26 00	6.0	10.3	7.6	7.5	5.9	8.8	12.4	6.9	5.0	11.8	9.5	12.8
28 00	6.4	10.8	8.0	7.9	6.2	9.3	13.0	7.2	5.3	12.4	9.9	13.4
31 00	6.8	11.6	8.5	8.4	6.5	9.8	14.0	7.6	5.6	13.3	10.7	14.3
48 00	8.9	15.1	11.5	11.0	8.5	13.0	18.4	9.8	7.4	17.3	14.2	18.5
50 00	....	....	....	....	....	....	....	....	....	....	....	....
53 00	9.8	16.0	12.3	11.7	9.1	13.7	19.6	10.5	7.8	18.4	15.1	19.6
55 00	9.8	16.4	12.6	11.9	9.3	14.0	20.1	10.7	7.9	18.8	15.5	20.0
74 00	....	....	....	....	....	....	....	....	....	....	....	....
96 00	13.8	22.5	18.4	16.7	13.2	19.3	28.1	14.3	11.3	25.7	21.7	27.2

THIRD SERIES.

Time.	H_2O	K_2CO_3.	KCl.	P_2O_5.	$KHSO_4$.	$CaSO_4$.	KCl and NH_4NO_3.	P_2O_5 and K_2CO_3.	P_2O_5 and $KHSO_4$.	$CaSO_4$ and $CaHPO_4$.	$CaHPO_4$.	NH_4NO_3.
H. M.												
30	....	....	....	....	....	....	1.0	1.0	....	1.0	....	1.0
38	....	....	1.0	....	....	....	....	....	....	....	....	....
42	....	....	....	....	....	....	....	....	....	....	....	....
45	1.0	1.0	....	....	....	....	....	....	....	....	....	....
50	....	....	....	....	....	....	....	....	....	....	1.2	....
2 00	1.5	1.7	1.9	1.5	1.0	1.5	2.4	1.9	1.0	2.2	1.8	2.0
4 00	2.0	2.5	2.9	2.2	1.3	2.1	3.5	2.8	1.3	3.2	2.9	2.7
7 00	2.4	3.6	4.1	3.0	1.8	3.0	5.0	3.8	1.7	4.6	3.4	3.8
24 00	4.2	7.2	8.5	6.0	3.5	6.0	10.7	8.0	2.9	10.0	6.9	7.8
26 00	....	....	....	....	....	....	....	....	....	....	....	....
28 00	4.6	8.0	9.7	6.7	3.9	6.6	12.0	9.0	3.2	11.2	7.7	8.7
31 00	4.8	8.5	10.2	7.1	4.1	7.2	12.7	9.6	3.5	11.9	8.1	9.6
48 00	6.0	11.0	13.2	9.2	5.5	9.5	16.5	12.3	4.2	15.3	10.3	13.3
50 00	6.3	11.2	13.8	9.4	5.9	9.8	17.0	12.7	4.3	15.8	10.7	13.8
53 00	....	....	....	....	....	....	....	....	....	....	....	....
55 00	....	....	....	....	....	....	....	....	....	....	....	....
74 00	8.1	14.2	17.8	12.0	7.4	12.6	21.6	15.9	5.5	20.0	13.3	18.2
96 00	9.7	16.6	20.8	14.0	8.8	14.8	25.3	18.4	6.5	23.4	15.4	21.7

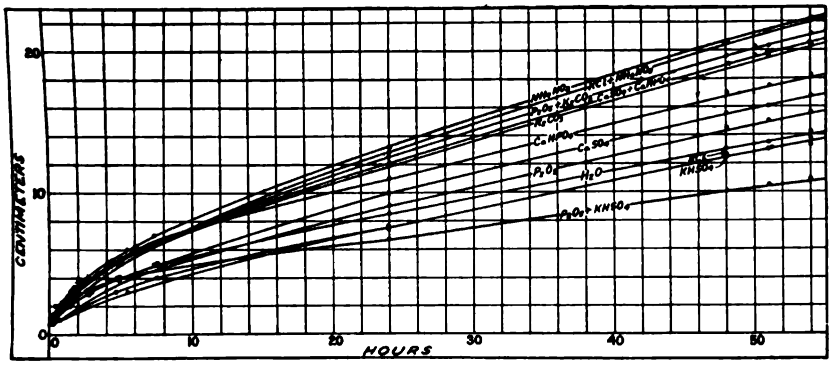

FIG. 18.—First series. Capillary movement of water in Volusia silt loam.

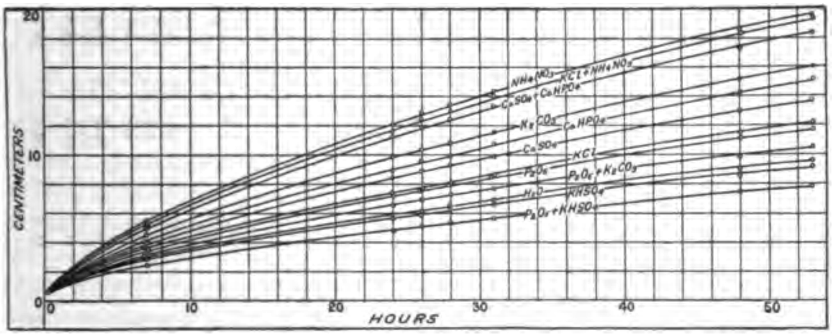

FIG. 19.—Second series. Capillary movement of water in Volusia silt loam.

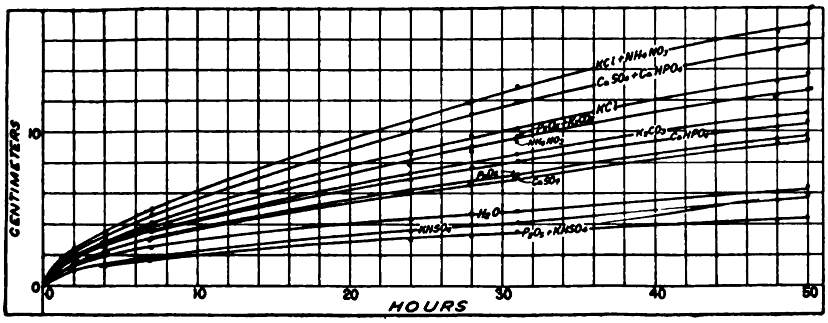

FIG. 20.—Third series. Capillary movement of water in Volusia silt loam.

TABLE XXII.—*Capillary movement of water in silt loam containing salts.*

FOURTH SERIES.

[Distances in centimeters.]

Time.	H_2O	K_2CO_3	KCl	P_2O_5	$KHSO_4$	$CaSO_4$	KCl and KH_4NO_3	P_2O_5 and K_2CO_3	P_2O_5 and $KHSO_4$	$CaSO_4$ and $CaHPO_4$	$CaHPO_4$	NH_4NO_3
H. m.												
03			1.0			1.0	1.0	1.0				
10		1.0								1.0		
14					1.0				1.0			
20												1.0
27			2.0			2.0	2.0	2.0			1.0	
33	1.0	2.0										
45	2.0				2.0					2.0		
1 07	3.0		3.0	2.0		3.0		3.0	2.0		2.0	2.0
1 20		3.0			3.0		3.0			3.0		
2 00	4.0	3.8	3.9	3.2	3.7	4.4	3.7	4.3	3.0	3.6	2.8	3.4
4 00	6.2	5.4	5.3	4.8	5.5	6.6	5.1	6.2	4.5	5.5	4.2	5.5
6 00												
7 00	9.0	7.5	7.0	6.8	7.8	9.0	7.0	8.5	6.3	7.5	5.7	7.9
24 00	18.0	14.7	14.0	14.2	15.7	17.5	14.5	16.8	13.2	15.2	11.8	16.0
27 00		15.7	15.0	15.0	16.4	18.5	15.5	18.0	13.9	16.0		
30 00												
31 00		17.0	16.2	16.2	17.7	19.9	16.7	19.2	15.0	17.2		
48 00	29.0	21.0	20.8	20.6	22.8	24.7	21.6	23.7	19.0	22.0		

FIFTH SERIES.

H. m.												
03												
10												
14		1.0						1.0				
20												
27										1.0	1.0	
33						1.0						
45	1.0		1.0	1.0	1.0		1.0					1.0
1 07												
1 20												
2 00	2.3	2.9	2.0	1.5	2.0	2.6	2.1	3.0	1.9	2.7	2.7	2.2
4 00	3.5	4.4	3.1	2.8	3.0	3.9	3.2	4.5	3.3	4.3	3.9	3.5
6 00	4.7	5.7	4.1	3.8	3.9	5.2	4.6	5.8	4.4	5.6	5.0	4.6
7 00												
24 00	11.9	13.1	10.4	9.5	9.7	12.5	11.4	14.0	11.0	13.4	11.9	11.8
27 00	12.9	14.0	11.3	10.2	10.5	13.5	12.3	15.1	11.9	14.5	12.9	12.8
30 00	14.1	15.0	12.2	11.0	11.3	14.5	13.3	16.2	12.8	15.6	13.9	13.8
31 00												
48 00	18.6	19.8	17.1	14.7	15.5	19.6	18.4	21.7	17.3	20.8	18.8	19.2

TABLE XXIII.—*Relative capillarity of soils with salts.*

Soil with salts.	Water position after 24 hours.	Soil with salts.	Water position after 48 hours.
	Cms.		*Cms.*
$P_2O_5+KHSO_4$	38.5	$P_2O_5+KHSO_4$	47.0
$KHSO_4$	41.9	$KHSO_4$	49.6
P_2O_5	46.0	H_2O	50.2
H_2O	47.1	P_2O_5	51.0
KCl	47.7	KCl	52.1
$CaHPO_4$	50.5	$CaSO_4$	59.7
$CaSO_4$	54.3	$P_2O_5+K_2CO_3$	62.6
K_2CO_3	56.7	$CaHPO_4$	63.7
$P_2O_5+K_2CO_3$	57.8	K_2CO_3	64.0
NH_4NO_3	60.6	$KCl+NH_4NO_3$	67.8
$KCl+NH_4NO_3$	61.0	$CaSO_4+CaHPO_4$	70.4
$CaSO_4+CaHPO_4$	61.9	NH_4NO_3	71.2

At first it is suggested that the acid salts lower the rate and the basic ones increase it; but calcium salts and ammonium nitrate seem not to conform to any such rule,-both of which seem to exert a greater influence than the acid or basic radical.

VAPOR PRESSURE.

PREVIOUS WORK.

Very little work has been done upon the effect of soluble salts upon the vapor pressure of soil moisture. From *a priori* considerations it would be expected that the presence of salt in the soil moisture would in general raise the surface tension and therefore lower the vapor pressure. Bovie[1] has made a few measurements on the vapor pressure of soil moisture to which sodium chloride was added.. His results indicate that the vapor pressure is lowered and that there is a transfer of water to the soil containing the salt, but his results also show that the amount of available soil moisture is lowered by the presence of salt, or rather the nonavailable moisture is increased, and only two measurements are given. King[2] has made some measurements on the amount of moisture in a soil manured and not manured and found that the first 3 feet of the manured soil was more moist than those of the unmanured soil. He attributed the difference to an increase in capillarity. This, however, is not the view held by Watson,[3] who states that King's moist surface foot of soil is due to decreased evaporation. In other words, the presence of the manure causes a lowering of the vapor pressure of the soil moisture. Watson, however, erroneously assumes that it is the coarse, insoluble part of the manure that affects the physical properties and that the soluble part has little or no effect.

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[1] Bul. Torry Bot. Club, 37, 290 (1910).

[2] Physics of Agriculture, p. 172 (1907).

[3] Iowa Acad. of Science, 16, 103 (1909).

METHOD OF EXPERIMENTATION.

The measurements made were of a qualitative character, no effort being made to determine the absolute value of the vapor pressure of soil moisture. The method followed was to place weighed quantities of soil, one containing salt and one without, in weighing bottles of practically the same size. Then enough water was added to each to bring the soil almost to saturation. Of course, the amount of water added in each case was exactly the same. These bottles after weighing were left open and placed in ordinary glass fruit jars and the top screwed down tightly. Weighings were made again after two or three weeks. In almost every case tried it was found that the soil containing the salt had lost more weight than the soil without salt.

RESULTS OF EXPERIMENTS.

Only two soils were used in the experiments and only two salts with each, but the soils were of different character, a clay loam and a sand, and one salt was alkaline carbonate and the other acid phosphate. The results of the measurements are shown in Table XXIV. These show that the evaporation was greater from the soils containing the salts, or that the vapor pressure is increased by the addition of the salts. These results are just the reverse of what would be expected from the phenomena in free solutions, and it is possible, though not probable, that some characteristics of the particular soils used were sufficient to cause this difference. If it is true that the vapor pressure of soil moisture is increased by the presence of salts there must be, besides surface tension, some (as yet unknown) factor in the solution which influences the physical condition of the soil.

TABLE XXIV.—*Relative loss by evaporation from soil and from soil with salt.*

Loss in grams of water in two weeks from—							
Cecil clay loam with—				Norfolk sand with—			
H_2O	K_2CO_3	H_2O	$CaHPO_4$	H_2O	K_2CO_3	H_2O	$CaHPO_4$
0.0538	0.1224	0.1286	0.1580	0.0430	0.0540	0.1030	0.1038
.1502	.1372	.0020	.1430	.0370	.0720	.1006	.0940
.0350	.0604	.0528	.0552	.0580	.0490	.0125	.0210
.0430	.0800	.0472	.0558	.1382	.1656	.0390	.0460
.0430	.0820	.0816	.1050	.0592	.0648	.0790	.0860
.0320	.0520	.1880	.2990	.0500	.0770	.0430	.0520

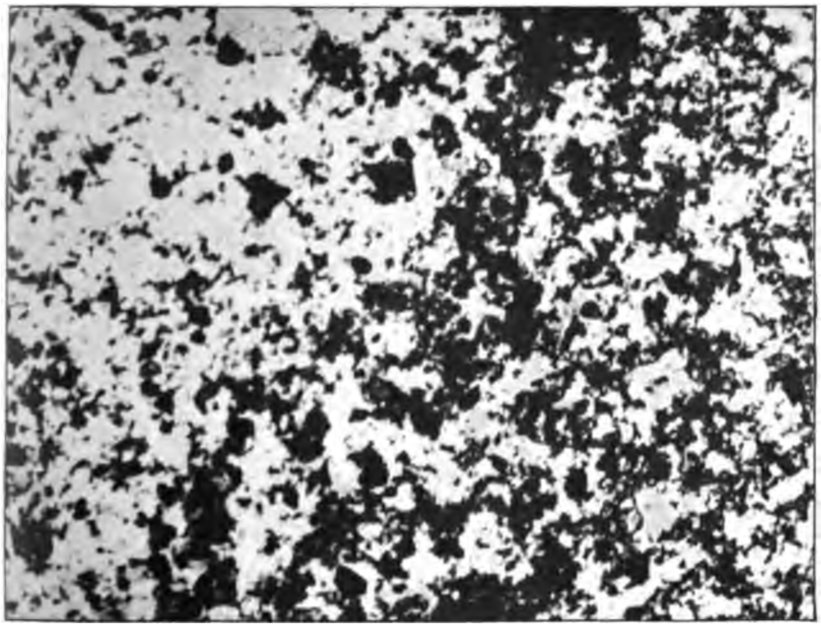

FIG. 1.—CLAY LOAM WITH POTASSIUM CARBONATE MOISTENED WITH WATER.

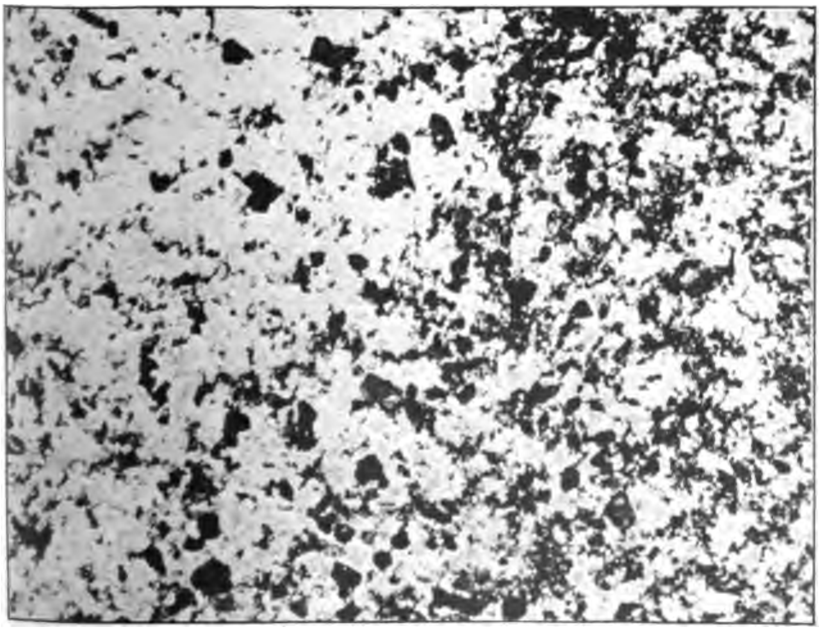

FIG. 2.—CLAY LOAM WITH POTASSIUM CARBONATE AFTER EVAPORATION OF WATER.

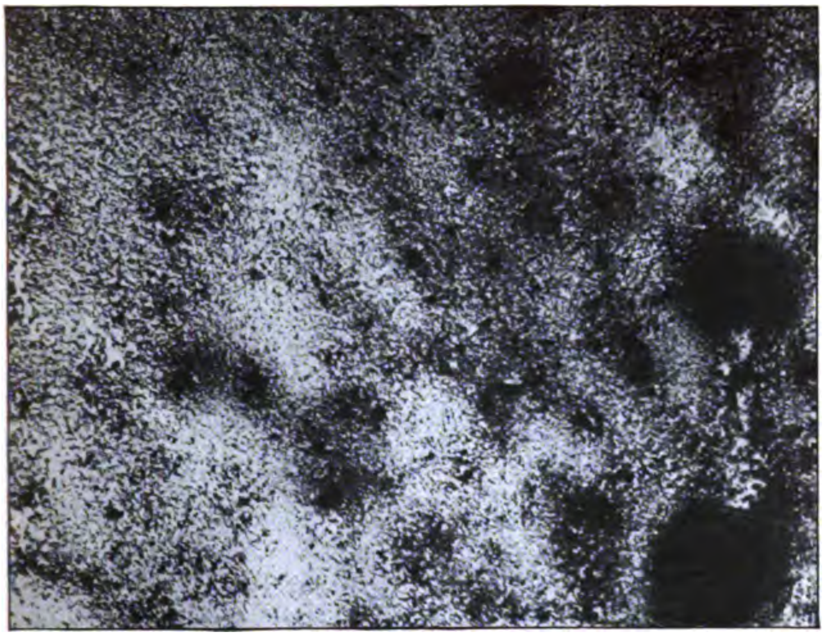

FIG. 1.—CLAY LOAM WITH MONOCALCIUM PHOSPHATE MOISTENED WITH WATER.

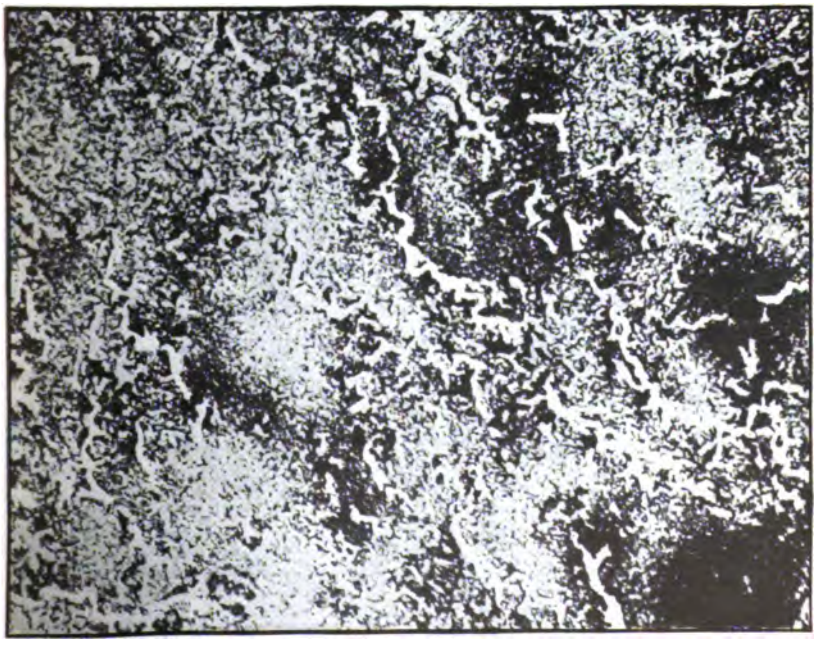

FIG. 2.—CLAY LOAM WITH MONOCALCIUM PHOSPHATE AFTER EVAPORATION OF WATER.

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MICROSCOPIC AND LANTERN EXPERIMENTS.

Having established the fact that the presence of small amounts of salts do exert a large influence on the physical properties of soils, as was shown in the penetration results, the measurements of apparent specific volumes, the rate of capillary movement in the soil, and in the change in vapor pressure, some observations were made with a microscope and a lantern in an effort to obtain visual evidence of the difference in structure produced by the salt. It was hoped that by the use of a binocular microscope the soil grains could be observed in perspective and a difference in their arrangement recorded. After numerous experiments with the microscope its use was abandoned. No satisfactory results could be obtained from the microscope because of the fact that such a limited field was covered. In a substance of such varied character and such heterogeneous composition as a soil, the field covered by the microscope is very likely not to be representative of the soil as a whole, or at least can not be regarded with any assurance as representative. The use of the lantern promised better results, for a large field could be used, but even here difficulties were encountered, which will be noted later.

METHOD OF EXPERIMENTATION.

The soil, placed in an ordinary Petrie dish, was moistened with water and then placed in a horizontal position on the condenser of the lantern. The lantern is so made that vessels containing specimens to be examined can be placed either in a vertical or horizontal position. The image of the soil particles was then thrown upon a screen or upon a photographic plate in a camera, if it was desired to preserve them. The water was then allowed to evaporate from the soil and the movement of the soil particles was noticed as the moisture content of the soil was reduced.

RESULTS OF EXPERIMENTS.

Experiments were made with sand, silt loam, clay loam, and clay, but only a few of the observations were preserved in photographs as representative of what took place in all the experiments. In the case of sand, the wet soil grains appeared more or less uniformly distributed. As the soil dried out, the particles could be seen to arrange themselves into groups, and the soil became much more open in structure. The same phenomenon was observed when salts were added, but in addition a difference is noted in the aggregation of the smallest particles present. When a clay or clay loam was used and the projection largely magnified, the small particles could be seen to be in almost continuous motion. In fact it was very difficult to obtain them sufficiently at rest to take a photograph. This effect is shown in

Plate VI. Figure 1 of this plate was taken while the soil was saturated with water; figure 2 after the water had evaporated. Although no movement was apparent to the eye, even in the greatly magnified projection, it is evident that there was movement. The plate was allowed to remain in the lantern, without being disturbed, until all the water had evaporated and then the second photograph taken. Again, it was absolutely impossible to break up all the aggregates of clay particles when mixing with water. And in observing the movement as evaporation proceeded the small clay particles were seen to move in streams about the edges of these aggregates and across from one lump to another by a straight path. This showed directly the movement of the small clay particles in a soil under the influence of moisture, and as all soils are more or less moist in practice, the effect of this moisture upon the movement of soil particles must, in the aggregate, be very great.

The photographs shown in Plates I to VI, inclusive, were all taken as described. Figure 1 shows in each plate the wet, and Figure 2 the dry soil. In each case the soil alone was moistened, the observation made, evaporation allowed to take place and the record photograph taken. The same soil then containing small quantities of potassium carbonate and monocalcium phosphate were treated in exactly the same manner. Just a portion of the photograph taken is here reproduced, but the same field is shown in each case. Plate I, figures 1 and 2, shows Norfolk sand alone moistened with water, and after the water has evaporated. On a close inspection it will be seen that some of the larger particles have changed their position during the evaporation, but the small clay particles seem to be fairly uniformly distributed in both cases, without any apparent grouping. The more open structure of the larger grains, where they are grouped, is very evident. This is much more strikingly seen by direct observation. As the sand grains are drawn together at one place and leave little openings at another, it gives the appearance of rapid flashes of light at numerous spots on the screen. In Plate II the Norfolk sand with potassium carbonate is shown, and in Plate III, with monocalcium phosphate. The only difference noticeable is in the grouping of the fine or clay particles. The same sort of opening of structure among the larger grains is noticeable. In the case of the calcium phosphate the small particles seem to collect in aggregates and these aggregates act as larger particles; with the potassium carbonate the small particles do not form aggregates by themselves, but appear to collect about the larger particles and to form aggregates with sand grains as centers. This is in accord with the theory that the carbonate causes a deflocculation and the small particles are simply drawn around the larger grains as evaporation proceeds. Monocalcium phosphate causes a flocculation and hence the aggregates observed. Where the presence of potassium carbonate causes a deflocculation there is a difference from the case in which simply water is present. On drying out, the fine particles in the soil with water alone do not collect so markedly about the larger grains; with potassium carbonate this grouping about larger particles is very marked. Plate IV represents the clay loam with water, and Plates V and VI with potassium carbonate and monocalcium phosphate. The same effect is noticeable that is seen in the sand; the effect of drying on the structure, the deflocculation of the small particles by potassium carbonate and the flocculation by monocalcium phosphate.

While the results showed what was to be expected, they can not show the whole structural difference in the soil. They are only an indication of a difference. In the soil in natural condition, the forces that act upon the grains may move them in any plane. In the lantern experiments, of necessity, a very thin layer of soil had to be used, and hence movement of the soil grains was restricted to one plane, and in addition, the friction of the glass upon which the grains rested was opposed to the movement. It can readily be seen then that forces which would produce large effects when allowed to act in any plane, might not produce a measurable effect when restricted to one plane. The photographs and observations do show an effect other than flocculation and deflocculation produced upon the structure of the soil by small amounts of salts present.

THE EFFECT OF SOLUBLE SALTS ON THE STRUCTURE OF A SOIL.

FACTORS INFLUENCING STRUCTURE.

In the discussion by Briggs [1] of the mechanics of soil moisture, the moisture film is declared to be the great factor in influencing the movement of moisture through the soil. Cameron and Gallagher,[2] however, first showed by measurements the relation of the moisture film to the structure of the soil. It is hardly necessary here to discuss this theory of the movement of soil moisture, as it has become generally accepted. The movement of soil grains under the influence of the moisture films is of more concern to us here.

If we consider the soil grains and the soil moisture, each has a movement dependent upon the other. The movement of soil moisture is dependent upon the mechanical composition (fineness of grains) of the soil, the structure (arrangement of particles) and the organic matter present. The effect of organic matter is not explained. Its presence may cause a change in structure, and if this is its only effect the moisture movement is dependent upon the mechanical composition and the structure of the soil only. The mechanical composition of any particular soil remains constant.

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[1] Bul. No. 10, Bureau of Soils, U. S. Dept. of Agr. (1897).

[2] Bul. No. 50, Bureau of Soils, U. S. Dept. of Agr. (1908).

On the other hand, the structure of the soil is dependent upon the amount of moisture or the thickness of the moisture films upon the soil grains, and the influence exerted by the films is dependent upon their surface tension. The surface tension is in turn dependent upon the substances dissolved in the water or mixed with it. So it is evident that the factors that enter into the movement of moisture or that determine the structure of the soil are largely and probably entirely dependent variables.

If two portions of soil are in contact, one of which contains a higher percentage of water than the other, there will be a movement of moisture toward the portion of lower percentage, due to the action of what we are pleased to call surface tension. But there will be a pull upon the soil particles also, and a consequent rearrangement or change of structure. The evaporation of water will also cause a change in the thickness of the moisture films surrounding the soil grains, with consequent rise of the surface tension, and as a result the particles of soil are pulled along in the film and the soil structure is altered. The collection in and movement of soil particles with the surface film of water can be easily observed by the use of the lantern, either on adding water to or allowing it to evaporate from the soil. From these considerations it would seem that surface tension is the greatest factor in influencing the structure of the soil as well as causing the movement of moisture in the soil.

In addition to the influence of surface tension there is another influence made evident in the flocculation and deflocculation phenomena. While these phenomena themselves may be due to surface tension at the solid-liquid surface, no definite relation has been established between them as yet.

RELATION OF EXPERIMENTAL RESULTS TO STRUCTURE.

The penetration measurements show that for the samples of soil used, the penetration values were increased by the addition of soluble salts for silt loam and decreased for clay loam, and likewise the apparent specific gravity is increased for silt loam, clay and sand, and decreased for clay loam. The character of the salts added to the soil does not appear to exert a very great influence, as shown in the curves of figures 12 to 15, inclusive. The curves seem to fall into two groups, but a general classification of the groups is not apparent. The decrease in the penetration and the apparent specific gravity for clay loam might suggest the influence of the clay particles; but the Susquehanna clay has a larger percentage of clay, and its apparent specific gravity is increased. Likewise the measurements of vapor pressure give results that would hardly be explained from the consideration of surface tension factors alone. In all the measurements the vapor pressure is lowered by the addition of salt, while presumably the surface tension is increased. The influence of some dependent variable, as yet unaccounted for, must cause the discrepancy between the results and the theoretical considerations.

FLOCCULATION AND ADSORPTION PHENOMENA.

In addition to the effects already noted, those of flocculation and adsorption are exerted in a solution containing soluble salts. It has been pointed out by Patten[1] that although in general alkalies will cause deflocculation, and acids a flocculation of suspended particles, a change in concentration may cause a change in the result produced. It is well known that soils are deflocculated generally by the addition of alkalies, but no study has been made of the concentration changes upon the deflocculation or flocculation. Nor has any such attempt been made in the experiments described in this bulletin, but several strengths of potassium carbonate, chloride, and potassium carbonate with phosphoric acid, were used and no difference could be observed in the effects upon the properties measured. In figure 21 is shown the curve for three concentrations of potassium chloride with silt loam. This same thing is shown for penetration of clay loam with potassium chloride and the volume change of silt loam with phosphoric acid, as may be seen by referring to figures 1 and 10. It is hardly probable that all of these strengths of solution would cause the same flocculation. The flocculating power of the salts, then, does not appear to be the controlling factor.

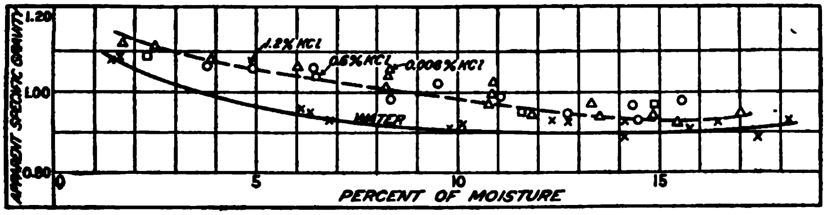

FIG. 21.—Moisture-apparent specific gravity results for Volusia silt loam.

Adsorption of soluble material has been shown to exert an appreciable influence upon the water-holding power of finely divided solids.[2] The hydroxides and carbonates seemed to lower the water-holding power and other salts to raise it. Adsorption and flocculation are likewise closely related.

From these considerations it becomes even more apparent that the effect produced upon the physical properties of a soil by the addition of soluble salt is composed of many complex and interdependent factors.

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[1] Am. Chem. Jour., 18, 608; Proc. Am. Electrochem. Soc., 9, 287 (1906).

[2] Patten & Waggaman, Bul. No. 52, Bureau of Soils, Dept. of Agr., p. 71 (1908); Ulrich, Forsch. Geb. Agr. Phys., 16, 406 (1893); 18, 63 (1895).

SUMMARY.

From the foregoing experiments and discussion it is evident that the causes producing a change of structure in the soil are many and complex.

It has been demonstrated, furthermore, that the addition of small amounts of soluble salts affect the physical properties, and therefore the structure of the soil.

Some results obtained are not explained by hitherto known facts and are apparently not in accord with theories regarding the action of salt solutions on solid particles.

From the results no predictions can be made regarding the specific direction or the amount of the action of salts on particular soils, but it can be asserted positively that there is a measurable change in the structure of a soil due to the addition of soluble salts. It is conceivable that there are causes producing changes other than those which are generally considered.

The effect of salts is more pronounced in a soil containing a large percentage of fine soil particles, and this leads to the conclusion that colloidlike clay particles are affected most by soluble salts, and in turn affect most the structure of the soil.

The actual nature of the condition produced in the smallest soil particles is not known beyond the fact that flocculation and deflocculation may be produced.

The photographs of soil layers, in addition to these effects, show an apparent difference in the grouping of the smaller aggregates with reference to the larger soil grains.

The fact that the problems are complex does not detract from the practical conclusion that soluble salts, whether they supply to a soil elements necessary for plant growth or not, may produce in the soil measurable changes in structure which in turn greatly influence plant growth.

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Issued December 15, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 83.

MILTON WHITNEY, Chief of Bureau.

A BENEFICIAL ORGANIC CONSTITUENT OF SOILS: CREATININE.

INTRODUCTION: IMPORTANCE OF BENEFICIAL SOIL CONSTITUENTS. OSWALD SCHREINER, Scientist in Charge Fertility Investigations.

I. THE ISOLATION OF CREATININE FROM SOILS.
EDMUND C. SHOREY, Scientist in Fertility Investigations.

II. THE ORIGIN OF CREATININE IN SOILS.
M. X. SULLIVAN, Scientist in Fertility Investigations.

III. EFFECTS OF CREATININE ON GROWTH AND ABSORPTION.
J. J. SKINNER, Scientist in Fertility Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., July 10, 1911.

SIR: I have the honor to transmit herewith the manuscript of a scientific paper entitled "A Beneficial Organic Constituent of Soils: Creatinine." This paper is the result of a study of the organic matter of the soil by a number of the soil scientists of this bureau.

The results of this investigation throw much light upon the problems of soil fertility and I therefore recommend their publication as Bulletin No. 83 of the Bureau of Soils.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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IMPORTANCE OF BENEFICIAL SOIL CONSTITUENTS.

By OSWALD SCHREINER,
Scientist in Charge, Fertility Investigations.

There have appeared a number of bulletins from this laboratory dealing with the nature and properties of soil organic matter. The extended study of this subject, about which so little definite information existed in chemical and agricultural literature, was undertaken as a result of the discovery of a harmful property in extracts from unproductive soils which was shown to be organic in character rather than inorganic. An investigational survey of organic compounds likely to occur in soils showed that some of these had decided effects on plant growth, and an examination of the organic matter of unproductive soils led to the discovery and isolation of several harmful constituents. The details of these investigations, as well as the effect of such substances in hindering plant growth, interfering with the normal processes of plant life and plant metabolism, have been given in the earlier reports of these investigations. All of these facts showed the great importance of more accurate knowledge concerning that most important and yet least understood soil constituent, the organic matter or humus of soils. A thorough inquiry into the nature of this material has been made in this laboratory and already a considerable fund of definite information is at hand. Starting without methods and with no definite organic soil constituent ever isolated from soil, the work has steadily progressed until to-day over 25 organic soil constituents have been isolated, definitely identified, and classified. The list of the compounds so far isolated varies from simple compounds, containing only carbon and hydrogen, to complex compounds, containing carbon, hydrogen, oxygen, nitrogen, and phosphorus. They are compounds which exist as such in living plants or arise from the decay or decomposition of the proteins, fats, nucleic acids, carbohydrates, and other plant and animal substances, as the result of purely chemical oxidations and reductions and through the intervention of molds, bacteria, protozoa, and other biological influences in soils. According to the factors operative in the decay of this plant and animal débris, the course of change will be different, resulting under one set of conditions in the formation of the abnormal and harmful constituents alluded to above and under other conditions in the formation of normal or beneficial organic constituents of soils.

It is an essential part of this survey of the organic matter in soils to learn the properties of the individual constituents and their effect on the life within the soil and on growing crops. Owing to lack of material and the difficulty of getting large amounts of the constituents in question, this inquiry is naturally a difficult and tedious one and consequently the determination of the effect on crop growth of all of the constituents isolated has not yet been feasible. So far as one of the constituents is concerned, this has been quite thoroughly done and the report made in a former bulletin. In the present bulletin the presence in soils of a constituent decidedly beneficial to growing crops will be emphasized. This soil constituent is creatinine, a nitrogenous compound, the isolation, identification, and chemical properties of which will be given in the first of the following papers, its occurrence in plants and seeds, and especially the fact that it can be found in soil and water in which plants are growing is presented in the second paper, and the effect of this compound on plant growth and its ability to serve as a direct source of nitrogen to the plant, in the third paper.

The three facts demonstrated by these investigations are of fundamental significance in soil fertility. The recognition of this directly beneficial soil constituent is no less important than the recognition that harmful soil constituents exist. The organic matter of soils has been considered almost wholly as having an indirect effect in agriculture, to be as it were merely a source for important elements like phosphorus and nitrogen. These researches show individual constituents to have decided effects by themselves in hindering or helping plant growth. This nitrogenous constituent appears to be as favorable as soil nitrates to crop production and even to be able to replace the latter in such a manner that the amount of nitrate absorbed is materially lessened in its presence while plant growth is increased. The amount in soils is, moreover, comparable with the amount of nitrates as usually found in agricultural soils. Creatinine is, however, only one of a long list of nitrogenous and phosphorus-carrying organic compounds of the soil and the remarks here made will probably find application to many other of these soil constituents.

The most beneficial manures under normal circumstances are those of organic origin, and the presence of such directly beneficial compounds, like creatinine, in well-rotted stable manure and in green manures, like cowpeas, goes far toward explaining why these manures are more beneficial to soil as a rule than are equivalent parts of fertilizer in the purely mineral forms.

The chief aim in the agricultural use of nitrogen is to convert this into nitrates by chemical and biological means, an operation far from simple, especially by distinctly chemical processes. The present researches are very suggestive of the fact that for agricultural purposes it may not be necessary to convert all nitrogen into nitrates, but that nitrogen of waste nitrogeneous materials in the industries can be converted into compounds of the nature here discussed and so make available to agriculture much nitrogen now lost because of the difficulty to convert it into nitrates. These, however, are matters for further investigation. The present bulletin will content itself with demonstrating that a nitrogenous constituent, creatinine, exists in soils, in manures, and in many plants and seeds, whereas hitherto it was recognized only in connection with products of animal origin; that it is beneficial to crops, and that it seems to be able to replace nitrates in aiding plant growth.

THE ISOLATION OF CREATININE FROM SOILS.

By Edmund C. Shorey,
Scientist in Fertility Investigations.

DISCOVERY IN SOILS.

In the course of investigations into the nature of the organic constituents of soils a crystalline organic compound was isolated and identified as creatinine.

Reactions indicating the presence of this compound were first observed in a solution of a portion of the soil organic matter obtained in the following manner: The soil was treated with 2 per cent sodium hydroxide solution for half an hour, and then without separation of the alkaline extract from the soil, acetic acid in slight excess was added and the acid solution filtered from the soil and precipitate formed. The acid filtrate was neutralized with sodium hydroxide and, without filtering, a solution of lead acetate added and the precipitate formed was separated by filtration. On the addition of ammonia to the filtrate a further precipitate was produced which was filtered off, washed, and decomposed by hydrogen sulphide. The filtrate from lead sulphide was concentrated to a small volume and was found to give the Jaffé, Weyl, and Salkowski color reactions for creatinine.

It was further found that if the filtrate from the neutral lead acetate precipitate was made alkaline with sodium hydroxide instead of ammonia, and the resulting precipitate decomposed and concentrated, the color reactions were obtained more strongly, indicating a more complete precipitation of the creatinine by this means.

From the known behavior of creatinine when treated with lead acetate in alkaline solution it was evident that neither of the methods of precipitation mentioned would result in complete separation of the creatinine present, and for the isolation of this compound recourse was had to other methods.

METHODS OF ISOLATION FROM SOILS.

ALKALINE EXTRACTION.

The method by which creatinine was first isolated from soils, and already noted elsewhere,[1] was to apply to an alkaline soil extract a method recommended by Balke[2] for the separation of purine bases, and used for that purpose in this laboratory.[1] This method depends on the fact that when there is precipitation of cuprous oxide from Fehling's solution by a reducing body, purine bases and some related compounds combine with the cuprous oxide and are found in the precipitate. Creatinine behaves in this way, as was first pointed out by Masche.[2]

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[1] Science, 33, 340 (1911).

[2] Jour. prakt. Chem. (2), 47, 537 (1893).

The method as applied to the isolation of creatinine from soils was carried out as follows: An alkaline extract of the soil, made by treatment for a short time with 2 per cent sodium hydroxide, was made exactly neutral with acetic or sulphuric acid and filtered. The neutral filtrate was heated to boiling and a little dextrose added and then Fehling's solution, slightly in excess of that required by the dextrose present. The precipitate formed was separated by filtration, well washed, and decomposed by hydrogen sulphide. The filtrate from the copper sulphide was concentrated to a small volume under reduced pressure, a small quantity of a concentrated solution of zinc chloride and a little sodium acetate added, and the whole allowed to stand several days. Within a few hours crystals began to form, and in 48 hours these were observed to have the characteristic appearance of creatinine zinc chloride. The crystals were separated from the mother liquor by filtration or, when the quantity of material was very small, by placing the whole mass on a porous plate. After separation the crystals were washed with a little cold water, suspended in water and boiled with some freshly precipitated lead hydroxide, filtered, and the filtrate concentrated to a small volume; on standing a short time crystals formed having the appearance, solubility, and color reactions of creatinine.

ALCOHOL EXTRACTION.

From another portion of the same soil from which creatinine had been obtained by the method just outlined, creatinine was also obtained by alcoholic extraction. About 100 grams of air-dried soil were extracted in a Soxhlet extractor for seven hours with 95 per cent alcohol. The alcohol was removed from the colored extract so obtained by evaporation, water being added to keep the volume constant. The aqueous solution was filtered from resinous and fatty matter and evaporated to a small volume under reduced pressure. The concentrated solution gave all the color reactions for creatinine and on treatment with zinc chloride gave, after standing two days, crystals of the characteristic creatinine zinc chloride.

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[1] Chemical Nature of Soil Organic Matter. By Oswald Schreiner and Edmund C. Shorey. Bul. 74, Bureau of Soils, p. 41 (1910); Jour. Biol. Chem., 8, 391 (1910).

[2] Zeit. anal. Chem., 1878, p. 134.

AQUEOUS EXTRACT.

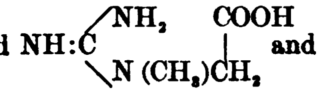
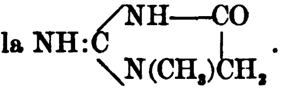
Creatinine was also obtained from the same soil by simple extraction with water. About 5 kilograms of soil were extracted with cold distilled water in a percolator until 8 liters of extract had been obtained. This extract was concentrated to about 100 cubic centimeters by evaporation under reduced pressure, and filtered from a small quantity of insoluble matter present. The solution so obtained gave all the color reactions for creatinine, and on treatment with zinc chloride, crystals of the characteristic creatinine zinc chloride were formed. From these, by treatment with lead hydroxide in the manner already described, crystalline creatinine was obtained.

THE CHEMISTRY OF CREATININE.

OCCURRENCE AND PROPERTIES.

Creatinine, $C_4H_7ON_3$, is found normally in human urine, and has been reported as found in a number of fluids and tissues for the most part of animal origin; in dogs' urine,[1] in the flesh of certain fish,[2] in the muscles of mammalia,[3] in beef extract,[4] in crab extract,[5] and among the products of certain bacteria.[6]

Its occurrence in plants, demonstrated in another section of this bulletin, has not heretofore been noted, and its occurrence as the result of bacterial growth has been noted but a few times.

Creatinine is the anhydride of creatine or methyl guanidine acetic acid  $\mathrm{NH{:}C}\begin{array}{l}\diagup \mathrm{NH_2}\quad \mathrm{COOH} \\ \qquad\qquad\quad | \\ \diagdown \mathrm{N\,(CH_3)CH_2}\end{array}$ and is represented structurally by the formula  $\mathrm{NH{:}C}\begin{array}{l}\diagup \mathrm{NH{-\!\!-}CO} \\ \qquad\qquad\ | \\ \diagdown \mathrm{N(CH_3)CH_2}\end{array}$. It is readily transformed into creatine by heating with acids or, as Folin and Denis have recently shown, by heating it with its water of crystallization under pressure.[7]

Creatinine is sparingly soluble in cold water and in alcohol and is insoluble in ether. It is easily soluble in hot water, and crystallizes from a hot saturated solution in monoclinic plates or prisms without water of crystallization. From a cold saturated solution it crystallizes in large plates containing two molecules of water. It forms crystalline salts with mineral acids and double salts with many mineral salts. The double salt with zinc chloride and hydrochloric acid $(C_4H_7ON_3HCl)_2\ ZnCl_2$ is easily soluble in water and alcohol, but if to a solution of this salt sufficient sodium acetate be added to neutralize the hydrochloric acid the salt $(C_4H_7ON_3)_2\ ZnCl_2$ is formed, and, being little soluble in water, is precipitated. The crystalline form of this salt is characteristic, being in the form of fine needles arranged in the form of balls or tufts showing a radiating structure, or when pure and in sufficient quantity, in the form of monoclinic plates. It is almost insoluble in alcohol, and has been used for the preparation of creatinine, and its characteristic crystalline form affords, when obtained, conclusive evidence of the presence of creatinine.

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[1] Voit, Jahr. Fortsch. Chem., 1867, 792.

[2] Krukenberg, Jahr. Fortsch. Thier. Chem., 1881, 344.

[3] Monari, Gazz. chim. ital. 17, 382 (1888).

[4] Kutscher, Zeit Nahr Genussmittl., 10, 528 (1905); 11, 582 (1906).

[5] Ackerman & Kutscher, Untersuch Nahr Genussmittl., 13, 183 (1907).

[6] Zinno, Riforma Medica, 9 (3), 806 (1893); Antanoff, Central. Bakt. Parasit, 48, 209 (1907).

[7] Jour. Biol. Chem., 8, 300 (1910).

COLOR REACTIONS.

Creatinine in water solution gives a number of color reactions that have been depended on largely as indicating or proving the presence of this compound in fluids such as urine.

Jaffé's reaction.—If a solution of creatinine be made alkaline with sodium hydroxide and then a few drops of picric acid solution added, a red color is formed.[1] The color, which is similar to that of a concentrated solution of potassium dichromate, becomes orange on dilution. A quantitative colorimetric method for determining creatinine based on this reaction has been devised by Folin[2] and has been almost universally adopted in determining the quantity of this compound in urine. In the use of this reaction for either qualitative or quantitative purposes the absence of other compounds that give a similar color or that give a color that would obscure the one given by creatinine must of course be assured. In urine the only compound of this nature likely to be present is acetone, the presence of which can of course be easily determined. In solutions or extracts, however, containing soil organic matter there is the possibility of the presence of other compounds that may simulate or obscure the color given by creatinine, but whose presence can not be definitely determined, because of lack of efficient methods. Levulinic acid and furfural both give the Jaffé reaction strongly, and while neither have been definitely identified as present in soils, there are some indications of the presence of the former, and the latter might very easily be present or formed in soil extracts at some stage in the operation.

Weyl's test.—A watery solution of creatinine to which a small quantity of a solution of sodium nitroprusside has been added gives on the addition of sodium hydroxide a red color which soon changes to yellow.[3] As with the Jaffé reaction, the presence of certain other compounds may interfere with the use of this test either by giving a color that obscures the one given by the test, or giving a similar one.

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[1] Zeit. physiol. Chem., 10, 399 (1896).

[2] Zeit. physiol. Chem., 41, 223 (1904).

[3] Ber. chem. Ges., 11, 2175 (1878). Arnold, Zeit. physiol. Chem., 49, 397 (1906).

Levulinic acid gives under the conditions of this test a color similar to that given by creatinine, and this test with others has been used to establish the presence of levulinic acid in the decomposition products of nucleic acid.[1] Furfural and the products resulting from heating pentose-yielding material with acid give a similar color, although in no case is the fading of the red color to yellow so pronounced as with creatinine. The dark-purple color given by sulphides in the presence of sodium nitroprusside and sodium hydroxide would of course obscure the color given by creatinine, and, as was noted in the case of Jaffé's reaction, there are probably in soil extracts unknown compounds that give either a similar color or one that would obscure the one given by creatinine.

Salkowski's reaction.—If the yellow solution resulting from Weyl's test be acidified with acetic acid and then heated, the solution turns green, then blue, and Prussian blue is precipitated if much creatinine is present.[2] Both levulinic acid and furfural give the final blue color and precipitate, but in the case of levulinic acid the solution after the addition of acetic acid and before heating is purple. The reagents alone will give the final blue color and precipitate if the solution before acidifying be allowed to become warm.

Since soil extracts or solutions prepared from them may contain compounds that are known to give color reactions similar to those given by creatinine, and since there is the possibility of the presence of others as yet unknown, it is evident that results obtained with the color tests usually considered indicative of the presence of creatinine can not be considered conclusive proof of the presence of this compound in the soils from which the soil extracts were prepared.

METHODS OF IDENTIFICATION.

When indications of the presence of creatinine are obtained by any of the color tests just described, this can best be confirmed and established by the preparation of the creatinine zinc chloride $(C_4H_7ON_3)_2ZnCl_2$. This salt, almost insoluble in alcohol and difficultly soluble in water, is formed when concentrated solutions of creatinine and zinc chloride are brought together in the absence of free mineral acids, a condition usually obtained by the addition of a little sodium acetate. When any large quantity of creatinine is treated in this way there is immediate precipitation, but when small quantities are being dealt with precipitation does not begin for several hours and is not complete for several days. The crystals of this salt are quite characteristic in form, although this form is so modified by the concentration of the solution, the presence of other bodies, and other conditions that they appear to differ widely. A study of the form assumed when the crystals first appear, and of their growth, and of the form assumed on recrystallizing, soon results in familiarity with the characteristic appearance, so that the compound can be readily identified, no matter what form it may assume. Usually it appears in balls with radiating structure, due to their being made up of fine needles. Under other conditions its first appearance may be in starlike plates which eventually assume the form of bunches of radiating needles or plates. If the crystallization is slow, the plates may grow to a well-developed form. Under still other conditions the radiating needles are bunched in tufts rather than balls. This last form is the one assumed by the pure compound when a concentrated solution is cooled rapidly. Some of the forms are shown in the photomicrographs of Plate I.

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[1] Inouye, Zeit. physiol. Chem., 42, 116 (1904).

[2] Zeit. physiol. Chem., 4, 133 (1880); 9, 127 (1885).

When sufficient creatinine zinc chloride can be prepared pure, its identification by method of preparation, solubility, and crystalline form may be supplemented by analysis, although once familiarity with the characteristic behavior and appearance of this compound is acquired, this is not essential. A preparation of creatinine zinc chloride made from an alkaline soil extract in the manner already described was purified by recrystallization, dried on a porous plate, and then in a desiccator, and nitrogen and zinc oxide determined in the following manner: A portion of the creatinine zinc chloride, 0.36 gram, was digested with a small quantity of sulphuric acid and a little potassium sulphate, as in the Gunning modification of the Kjeldahl method for total nitrogen. The resulting solution was made alkaline with sodium hydroxide and distilled into standard acid in the usual manner. After the removal of the ammonia by distillation the solution was made acid with acetic acid and the zinc in solution precipitated by hydrogen sulphide, the zinc sulphide collected, the precipitate and filter paper treated with nitric acid, dried, and carefully ignited and weighed as zinc oxide. The analysis gave the following figures:

	Found.	Calculated for $(C_4H_7ON_3)_2ZnCl_2$.
N....	23.22	23.16
ZnO .	22.31	22.45

The formation of free creatinine from creatinine zinc chloride by boiling with lead hydroxide in the manner already described, the crystallization of the creatinine so obtained, and observations regarding its crystalline appearance, solubility, and color reactions, may be resorted to in further confirmation of the identity of the compound. The crystalline appearance of creatinine, monoclinic plates or prisms, one form of which is shown in the photomicrograph of Plate I, is, however, not characteristic enough to form the basis of identification.

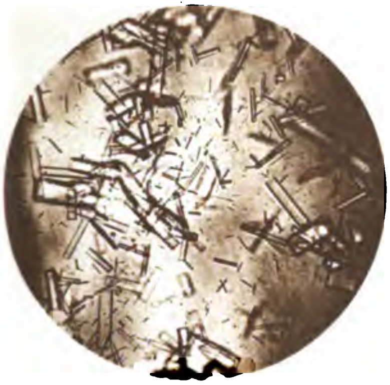


FIG. 1 - CREATININE

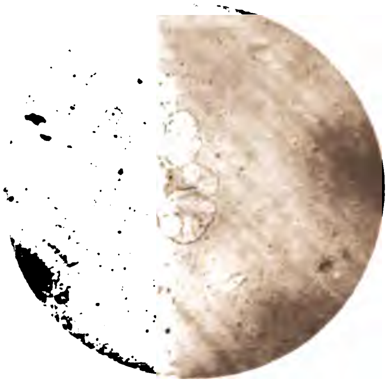


FIG. 2 - CREATININE ZINC CHLORIDE (CONCRETIONS)

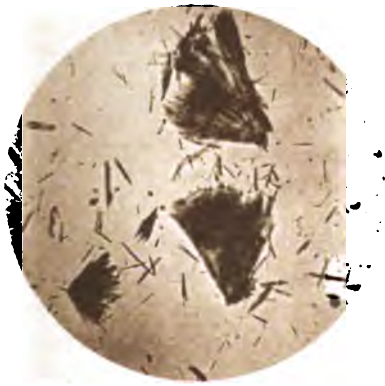


FIG. 3 - CREATININE ZINC CHLORIDE (TUFTS)

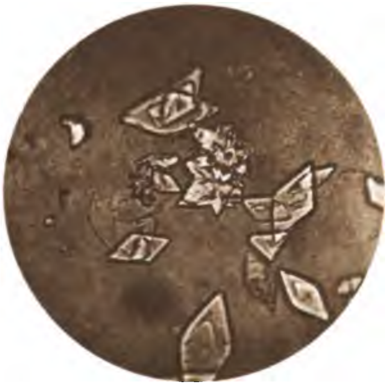


FIG. 4 - CREATININE ZINC CHLORIDE (PLATES)

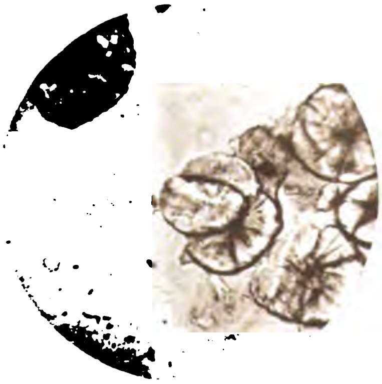


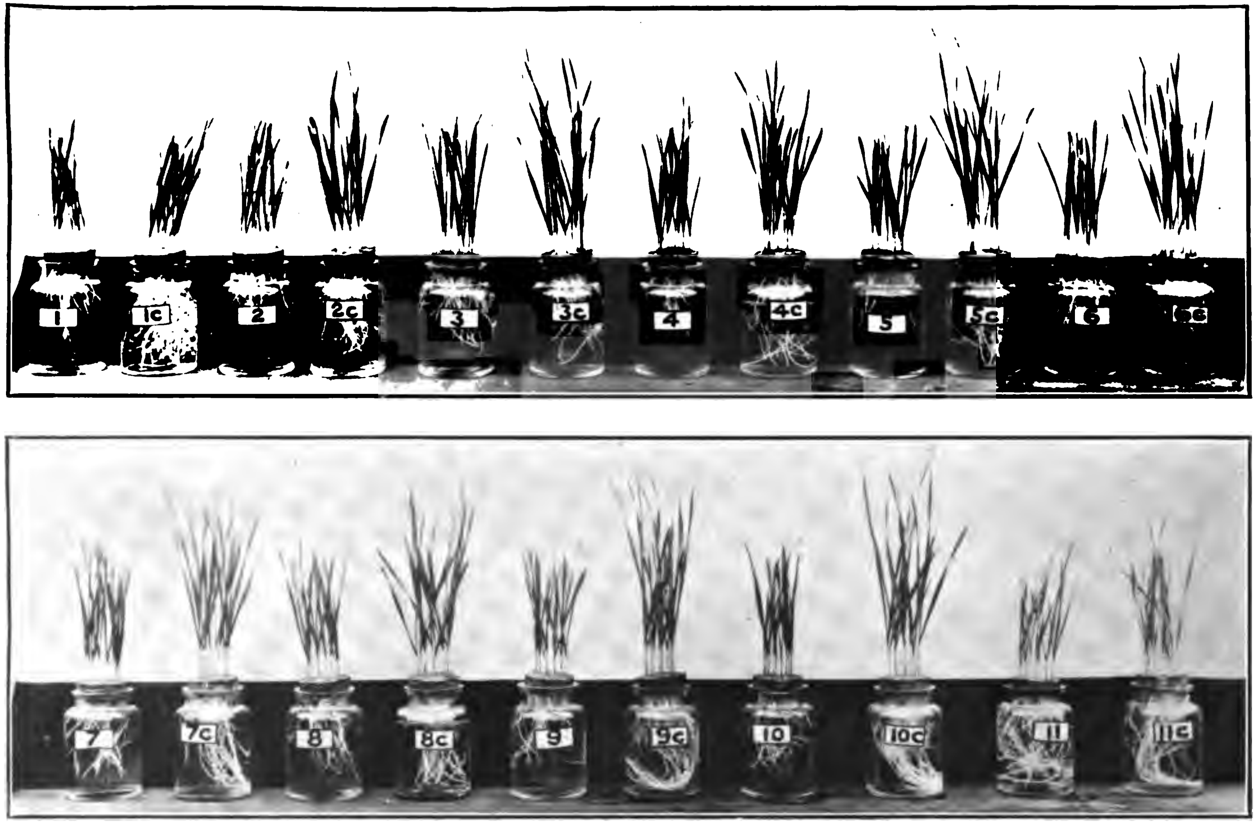
FIG. 5 - CREATININE ZINC CHLORIDE FROM CREATININE OF WHEAT

FIG. 6 - CREATININE ZINC CHLORIDE FROM CREATININE OF CLOVER

PHOTOMICROGRAPHS OF CREATININE FROM SOILS (FIG. 1), CREATININE ZINC CHLORIDE PREPARED FROM IT (FIGS. 2, 3, AND 4), AND CREATININE ZINC CHLORIDE PREPARED FROM THE CREATININE OF WHEAT AND CLOVER (FIGS. 5 AND 6).

M 10 U

PLATE II.



WHEAT PLANTS GROWING IN CULTURE SOLUTIONS WITH AND WITHOUT CREATININE, AND CONTAINING VARIOUS PROPORTIONS OF POTASH AND PHOSPHATE BUT NO NITRATE.

EXISTENCE OF CREATININE IN SOILS.

At this point the question naturally arises whether the isolation of creatinine by the methods described indicates or proves the presence of creatinine as such in the soil. In deciding this question in the case of other organic compounds isolated from soils the conclusion that the compounds in question must be in the soil as such was based on the fact that all the knowledge of the behavior of the compounds and their antecedents indicated that they could not be formed by any of the treatments to which the soil or soil extracts had been subjected. In the case of creatinine the question is complicated; first, by the fact that nothing is definitely known regarding its antecedents, i. e., what complex molecule, if any, it is derived from, no matter where found; and, second, by the fact already mentioned that creatinine is readily changed to creatine and vice versa according to the conditions imposed. Consequently, from general considerations only, it might seem that the creatinine isolated by methods which involve chemical reagents and heat might be derived from creatine or some unknown more complex body from which creatinine was easily split off. More detailed consideration, however, of the methods involved effectually disposes of the possibility that the creatinine is wholly derived from creatine. While the transformation of creatine and creatinine back and forth into each other is comparatively easy, Folin has shown[1] that it is not so easy as many investigators have assumed. All the operations in the methods used except the final concentration were such as would result in the change of creatinine back to creatine rather than otherwise. The alkaline extraction and boiling with Fehling's solution would no doubt bring about this change to some extent so that the creatinine finally obtained was that which had resisted this treatment. The final concentration of the aqueous solution at a low temperature might form some creatinine from creatine, but investigation has shown that this change could be but slight and could never involve the whole of the creatine if it were present. Treatment of these solutions by boiling for several hours with acid resulted in but slightly increased colorimetric readings for creatinine. In other words, the small quantity of creatine present shown by this method was out of all proportion to what would remain after evaporation under reduced pressure if creatine only had been present in the original solution.

The question of the possibility of the creatinine obtained being formed during the treatment from some more complex antecedent easily broken down unfortunately can not be disposed of until some definite information regarding such a complex, if there is one, is available.

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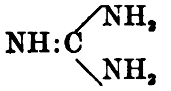
[1] The Chemistry and Biochemistry of Creatine and Creatinine. Festkrift Olof Hammarsten, III.

In the light of all the knowledge available and on consideration of the bearing of the methods on the final product it seems safe to conclude that a considerable portion at least and probably all of the creatinine isolated from soils is present in the soils as such.

RELATION OF CREATININE TO OTHER COMPOUNDS.

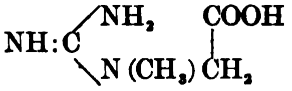
With the question of the possible antecedent of creatinine in mind it may be well at this point to consider its relation structurally to other compounds. Creatinine, as has been stated, is the anhydride of creatine or methyl guanidine acetic acid, and the relation of guanidine, creatine, and creatinine is shown as follows:

Guanidine.



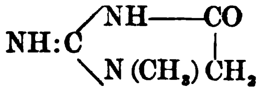
$$\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH_2}\\ \mathrm{NH_2}\end{matrix}\right.$$

Creatine.



$$\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH_2} & \mathrm{COOH}\\ & |\\ \mathrm{N(CH_3)} & \mathrm{CH_2}\end{matrix}\right.$$

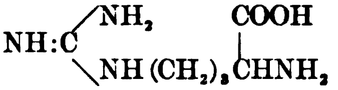
Creatinine



$$\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH}\text{——} & \mathrm{CO}\\ & |\\ \mathrm{N(CH_3)} & \mathrm{CH_2}\end{matrix}\right.$$

Arginine, a compound that occurs in plants and animals and which has been found in soils, is guanidine α-amino normal valerianic acid, and its relation structurally to the compounds just mentioned is shown by the formula:

Arginine.

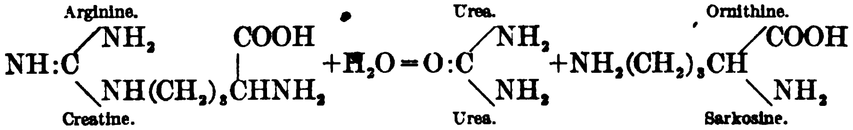


$$\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH_2} & \mathrm{COOH}\\ & |\\ \mathrm{NH(CH_2)_3} & \mathrm{CHNH_2}\end{matrix}\right.$$

Guanidine has been found in plants[1] and in the autodigestion of certain animal organs,[2] and the relationship evidently existing between this simple compound and the more complex arginine and of both to creatinine is of interest and suggestive of a common origin.

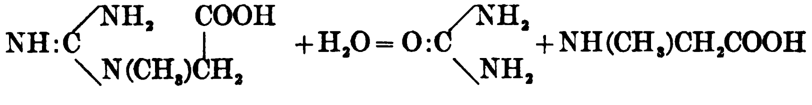
The close relationship between arginine and creatine and consequently of creatinine is shown by their behavior when heated with barium hydroxide. Under these conditions arginine decomposes into urea and ornithine, while creatine gives urea and sarkosine or methyl glycocoll:

Arginine. Urea. Ornithine.



$$\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH_2} & \mathrm{COOH}\\ & |\\ \mathrm{NH(CH_2)_3} & \mathrm{CHNH_2}\end{matrix}\right. + \mathrm{H_2O} = \mathrm{O{:}C}\left\langle\begin{matrix}\mathrm{NH_2}\\ \mathrm{NH_2}\end{matrix}\right. + \mathrm{NH_2(CH_2)_3CH}\left\langle\begin{matrix}\mathrm{COOH}\\ \mathrm{NH_2}\end{matrix}\right.$$

Creatine. Urea. Sarkosine.



$$\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH_2} & \mathrm{COOH}\\ & |\\ \mathrm{N(CH_3)} & \mathrm{CH_2}\end{matrix}\right. + \mathrm{H_2O} = \mathrm{O{:}C}\left\langle\begin{matrix}\mathrm{NH_2}\\ \mathrm{NH_2}\end{matrix}\right. + \mathrm{NH(CH_3)CH_2COOH}$$

The same relationship is shown in the synthesis of both compounds. Creatine has been synthesized from sarkosine and cyanamid,[3] while the synthesis of arginine has been brought about by the action of cyanamid on ornithine.[1]

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[1] Schulze, Ber. chem. Ges. 26, 658 (1893).

[2] Otori, Zeit. physiol. Chem., 42, 453 (1893).

[3] Stecker, Jahr. Fortsch. Chem., 1868, 686.

RELATION OF CREATININE TO OTHER ORGANIC SOIL CONSTITUENTS.

Of the two compounds just mentioned as being related to creatinine structurally, arginine only has been found in soils and only infrequently and in very small quantities. Since arginine is a constant decomposition product of protein it must enter into the organic material added to soils, and the evidence at hand indicates that it soon disappears as such. Guanidine, although it has been found in plants, does not seem to be a usual soil constituent, and although it has been looked for in a number of soils it has not yet been found. The purine bases bear a relation to guanidine and through it to creatinine, and it is worthy of note that guanine, the only commonly occurring purine base up to the present not found in soils, yields guanidine on oxidation. Guanine is, however, a constituent of organic fertilizers such as guano. The possible connection of creatinine with this purine group, while of interest, is in the present state of knowledge, however, purely speculative.

The possible relation of creatinine to more complex bodies found in the soil or added to soil in dead vegetation is still more obscure, but a few observations made in this connection are worthy of record. Nucleic acids of unknown constitution have been found in several soils.[2] Both nucleic acid from soil and yeast nucleic acid prepared by Merck have been found to give the color reactions for creatinine after heating or even warming for a few minutes with dilute hydrochloric acid. From a solution of yeast nucleic acid treated in this way crystalline creatinine zinc chloride was prepared. It was found, however, that on washing the nucleic acid with cold dilute hydrochloric acid the nucleic acid no longer had the property of giving creatinine on heating with acid. The hydrochloric acid washings, however, after heating showed the creatinine reactions. Whether the explanation of this lies in the inclusion of some creatine in the nucleic acid or whether creatinine is actually split off from the nucleic acid or some complex included with it is as yet unknown. Phytin, or oxymethylene diphosphoric acid anhydride, is an organic compound that occurs in the seeds of many plants and must find its way into the soil. So far, this compound has not been isolated from any soil, but it was found that a crude preparation prepared from wheat bran gave on heating with hydrochloric acid a solution which gave the color reactions of creatinine, and from this solution crystals of creatinine zinc chloride were prepared. On purifying the phytin, however, in the usual way by precipitating it several times as the barium salt[1] it likewise no longer had this property.

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[1] Schulze and Winterstein, Ber. chem. Ges., **32**, 3191 (1899); Zeit. physiol. Chem., **34**, 128 (1905).

[2] These researches on nucleic acid in soils will be reported more fully later.

PRESENCE OF CREATININE IN MANURES.

The relation of creatinine to plants and plant products generally is treated in a subsequent section of this bulletin, and the only further observations that will be made here bearing on the relation of creatinine to soil organic matter has to do with that added in agricultural practice, viz, organic manures. Creatinine has been found both in stable manure and in fresh cowpea vines as used in green manuring. A sample of well-rotted stable manure was extracted with water and the solution allowed to stand until further fermentation had ceased. From this extract creatinine was isolated by precipitation with Fehling's solution in the same manner as from soil extracts. The resulting solution gave the color reactions for creatinine and crystals of both creatinine zinc chloride and creatinine were prepared from the material isolated. Green cowpea vines were crushed and extracted with cold alcohol, the alcohol evaporated at a low temperature, and water added to keep the volume constant and the solution filtered from insoluble matter. From this solution creatinine zinc chloride was prepared by precipitating the creatinine with Fehling's solution and subsequent treatment with zinc chloride and also by treating the concentrated aqueous solution directly with zinc chloride.

ESTIMATION OF CREATININE IN SOILS.

The work so far done on the quantitative determination of creatinine in soils is but preliminary and no definite statement regarding the quantity present in soils can be made other than that it is small and apparently but a small portion of the total organic matter. The following facts bearing on this question were established. It is much more easily extracted from soil by alcohol than by water. Usually enough could be obtained by extracting 100 grams of soil with alcohol to establish its identity, but to accomplish this by aqueous extraction several kilograms of soil were usually necessary. In spite of this fact, alcohol extraction does not offer an available method for quantitative determination, as is shown by the following experiment: One hundred grams of soil were extracted with alcohol until the concentrated extract no longer gave any reaction for creatinine. Ten milligrams of creatinine were then added and the soil extracted with alcohol again, and the creatinine determined colorimetrically in the extract obtained. After 14 hours of continuous extraction only three-tenths of a milligram of creatinine was found in solution, and a second extraction of seven hours gave an amount too small to be determined. The color obtained was not greater after heating these extracts with acid, showing that the creatinine had not been extracted and changed to creatine. Since both water and alcohol extraction seemed unavailable as the basis of a method, attention was given to alkaline extraction. In attempting to carry this out quantitatively several difficulties are met. The complete extraction of the organic matter from soil with dilute alkali is slow and results in a very large volume of solution. Again this solution is dark colored and the use of a colorimetric method is out of the question unless there is removal of the color and concentration of the solution. It is possible that alkaline extraction and precipitation of the creatinine from the solution with Fehling's solution or in some other way will ultimately afford a means of determining this compound in soils, but so far these attempts have not given satisfactory figures.

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[1] Patten and Hart, Am. Chem. Jour., 31, 564 (1904).

The quantity of creatinine that has been found in soils by any of the methods tried, while small, and representing but a small portion of the organic matter, is by no means negligible, being usually several parts per million of soil and usually equal to and sometimes in excess of the quantity of nitrates normally present.

There is every indication that in no case was there complete extraction of the creatinine, and it is moreover possible that this organic soil constituent is a fluctuating quantity, being generated by bacterial or other biological agencies in the soil under certain conditions, and being changed or removed from the soil by growing plants under other conditions.

DISTRIBUTION OF CREATININE IN SOILS.

The initial work on the isolation of creatinine from soils was done with a sample of Volusia silt loam from New York. The sample was from a field that had been in cultivation for many years. At the time the sample was taken and for several years previous the crops on the field had been very poor. So far as could be ascertained the field had never had any application of either commercial fertilizer or stable manure.

After the identity of the compound isolated from the Volusia silt loam was established as creatinine a number of other samples of soil were examined for the presence of this compound. Comparatively few soils have been examined, but so far no soil has been found in which the presence of creatinine was not indicated by the color reactions given by the extract.

Creatinine zinc chloride in addition to color reactions were obtained from samples of the following soils:

Frankstown stony loam from Pennsylvania. This sample was taken from a field that had been in cultivation 30 years, but had recently lain idle for 3 years. When put in cultivation again the crops were still very poor.

Clarksville silt loam from Kentucky. This sample was from an area where the crop yields were fair and the soil responded well to applications of stable manure.

Dunkirk clay from New York. Fair crop yields had been obtained on field where the sample was taken.

It would seem, then, that creatinine is at least a frequently occurring and probably a normal and constantly occurring constituent of soils. While the soils examined have all been under cultivation some years there is no theoretical reason for concluding that virgin soils differ from cultivated ones in this respect except perhaps in quantity.

SUMMARY.

In this section of this bulletin the isolation of a crystalline organic compound is described. This compound contains nitrogen and has been identified as creatinine.

Several methods by which the compound has been obtained from soils are described and the chemistry of creatinine and methods of identifying it are discussed.

The relation of creatinine to other organic compounds is pointed out and certain observations regarding the possible connection between creatinine and other organic soil constituents are made.

The occurrence of creatinine in organic fertilizers, such as stable manure and cowpea vines, that are added to soils in agricultural practice has been established, and it has been shown that creatinine occurs in soils of widely different type and from widely separated areas.

It is pointed out that while the quantity of creatinine in soils is small it is not negligible, being comparable to the quantity of nitrates normally present. It is further pointed out that the quantity of creatinine probably is, like the nitrates, a fluctuating quantity.

THE ORIGIN OF CREATININE IN SOILS.

By M. X. Sullivan,

Scientist in Fertility Investigations.

In this paper are presented the results of experiments which throw some light on the question of the origin of creatinine in soils. The particular phase of the question studied is the presence of creatinine in plants and consequently in plant débris and the passage of the creatinine into the soil either by the disintegration of the plant débris or as a result of cell sloughing or direct passage from the living plant. Other possible origins of this soil constituent, such as its introduction in the animal excreta of stable manure or the formation by microorganisms, are not considered here.

Unless present in exceedingly small quantities creatinine gives certain color reactions. These reactions are: (1) Jaffé's reaction,[1] a red color with picric acid and a few drops of sodium hydroxide. With excess of alkali and on acidifying, the red color is discharged. (2) Weyl's reaction,[2] a ruby red color when a few drops of sodium nitroprusside are added to a creatinine solution and the mixture is made alkaline with sodium hydroxide. The red color soon turns yellow.[3] (3) Salkowski's reaction,[3] a greenish-blue color on adding an excess of acetic acid and warming the yellow solution obtained in Weyl's test. The greenish-blue color is in turn replaced by a blue color or a precipitate of Prussian blue.

The absence of these color reactions is a sure test that creatinine is absent or present in traces only. The occurrence of the color reactions, on the other hand, is but a presumptive test that creatinine is present, especially in the case of soil or plant extracts, since other substances show these reactions. When, however, no other substances which give these reactions are present in a solution, as in the urine, for example, the color reactions are decisive tests for creatinine and the Jaffé reaction has been made good use of as a quantitative test by Folin[4] and others.

The double salt of creatinine and zinc chloride is an important test for creatinine. It is formed best when zinc chloride and sodium acetate are added to a neutral or nearly neutral concentrated alcoholic solution of creatinine. The sodium acetate is added in sufficient quantity to neutralize any mineral acid that might be present since the characteristic double salt does not form in the presence of dilute mineral acids.

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[1] Zeit. physiol. Chem., 10, 399 (1886).

[2] Ber deutsch. chem. Ges., 11, 2175 (1878).

[3] Zeit. physiol. Chem., 4, 133 (1880); 9, 127 (1885).

[4] Zeit. physiol. Chem., 41, 223 (1904).

Though the literature pertaining to the biochemistry of the animal organism is filled with references to creatine and creatinine,[1] the possibility of the occurrence of these substances outside of animal products has not been investigated hitherto to any great extent. Zinno,[2] however, found that cultures of certain bacteria in peptone-salt solution gave Weyl's, Salkowski's, and Jaffé's reactions for creatinine, and he isolated the creatinine as creatinine zinc chloride. Later Antonoff,[3] relying merely on Weyl's reaction, reported the formation of creatinine by many bacteria in peptone-salt solution.

Prior to the present paper, however, creatinine has never been reported in vegetable matter, although it has been demonstrated often in the flesh of plant-eating animals.

In the present experiments the criteria for creatinine were: (1) The color reactions, especially Jaffé's and Salkowski's; (2) the formation of the characteristic double salt of creatinine and zinc chloride; (3) the regaining of creatinine from the zinc salt by boiling with lead hydroxide with a resulting solution which gave the color reaction

CREATININE IN PLANTED SOIL.

When the concentrated water extracts and water-glycerine extracts of a soil recently cropped in the greenhouse were boiled with Fehling's solution, there was more or less reduction of the copper with the formation of a greenish-white precipitate. The character of the precipitate suggested the presence of purine bases and creatinine in the soil solution, and it became of great interest to determine (1) whether or not the water and glycerine extracts of the cropped soils contained these compounds; (2) whether or not there was a relation between the content of these compounds in the soil and the growth of the crop. As regards the purine bases, it may be said in passing that by appropriate means their presence in the extracts was demonstrated. The main interest, however, was in creatinine for which the water and glycerine extracts of several soils recently cropped in the greenhouse were tested.

Arlington clay loam.—A sample of Arlington clay loam, upon which cowpeas had been grown for four years, was planted with wheat in paraffin wire pots and the cultures kept in the greenhouse for three weeks. Then the wheat seedlings were cut close to the soil.

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[1] For review of literature see Magnus Levy, Van Noorden's Handbuch der Pathologie des Stoffwechsels, 1906, 1, 137; Hoogenhuyze and Verploegh, Zeit. physiol. Chem., **46**, 415 (1905); Mellanby, Jour. Physiol., **36**, 447 (1908); Shaffer, Am. Jour. Physiol., **23**, 1 (1908).

[2] Riforma Medica (3), **9**, 806 (1893).

[3] Centr. Bakt. Parasitenk., **43**, 209 (1907).

The samples from the pots were combined and were sifted through a one-eighth inch mesh sieve. For the water extracts, 3 kilograms of the soil were extracted with 6 liters of water for 24 hours, with frequent stirring, especially in the early stages of extraction. For the glycerine extracts, 3 kilograms of soil were treated with 1,200 c. c. of pure glycerine for 12 hours, when 4,800 c. c. of water were added and the mixture stirred and allowed to stand 12 hours longer. The glycerine itself gave no creatinine test.

The water extract was filtered through paper and 2,500 c. c. were concentrated to a small bulk. The solution was then made slightly acid with hydrochloric acid and was treated with a large volume of alcohol. After a time a slight precipitate formed. The filtrate concentrated to about 20 c. c. gave Jaffé's and Salkowski's tests for creatinine. The glycerine extracts similarly concentrated to a small bulk gave stronger tests for creatinine. The concentrated glycerine extract of 2,500 c. c. of the original solution was sirupy from the glycerine. The sirupy concentrated glycerine extract was boiled with Fehling's solution and the mixture was filtered. The precipitate was suspended in water and freed from copper by means of hydrogen sulphide. The filtrate from the copper sulphide was concentrated as far as possible on the steam bath and was still found to contain some glycerine. To the concentrated solution, zinc chloride and sodium acetate were added with the formation of a white precipitate. In 24 hours, colorless rosettes of creatinine zinc chloride appeared.

Dunkirk clay.—About 8 kilograms of Dunkirk clay upon which wheat had grown for three weeks in the greenhouse were extracted for 20 hours with 6 liters of a 20 per cent glycerine solution. The supernatant liquid was poured off, the soil pressed in cloth in a press, and the combined solutions filtered through paper. The filtrate, concentrated to a small bulk, gave a strong Jaffé's reaction for creatinine. By the same procedure as used in the case of the Arlington clay loam above, the presence of creatinine was demonstrated by the formation of the creatinine zinc chloride.

Dutchess silt loam.—In the water extract of Dutchess silt loam and in the glycerine extract, creatinine was demonstrated in the same way by means of the double salt of zinc chloride and creatinine.

The creatinine zinc chloride crystals from the Arlington clay loam, the Dunkirk clay, and the Dutchess silt loam were boiled separately with freshly precipitated lead hydroxide. The filtrates were concentrated to a small bulk. All the concentrated solutions gave Jaffé's and Salkowski's tests. How much of this creatinine, which exists in the concentrated extracts in but small quantities, is present as such in the original extract can not be told, since in the process of concentrating some would be formed from creatine if present.

Creatinine was also found in the glycerine extract of the Arlington clay loam as it came from the field. As judged by the quantity of the double salt of creatinine zinc chloride obtained from the glycerine extracts of Arlington clay loam, planted and unplanted, similarly treated as regards concentrating, precipitating by Fehling's solution, freeing from copper by hydrogen sulphide, concentrating the filtrate from the sulphide and adding zinc chloride and sodium acetate, the extract of the soil planted and kept in the greenhouse for three weeks contained more creatinine than did the extract from the same soil unplanted used as a control. The increased amount of creatinine in the planted soil must have come (1) from an increased activity of microorganisms on the plant débris and plant constituents and on the organic matter of the soil, or (2) directly from the growing plants.

CREATININE IN THE WATER IN WHICH SEEDLINGS HAD GROWN.

Since creatinine was found in the extract of soil on which wheat had grown for several weeks, it seemed possible that it might exist in water in which wheat seedlings had grown. Wheat was soaked for about five hours in water, and was then placed with a little water in an enameled pan to germinate over night. The seeds with the plumule just showing were then placed on a perforated aluminum disk which was floated on water by means of four air-tight glass tubes. In two days the water was changed. The water collected from six pans, about 12 liters in all, was concentrated on the steam bath to 300 c. c. To the concentrated solution a few cubic centimeters of concentrated hydrochloric acid and 1 liter of alcohol were added. In a short time a flocculent precipitate settled out. This precipitate gave a good pentose reaction with orcin and hydrochloric acid, contained phosphoric acid, and gave a slight xanthine test and probably contained nucleic acid. The filtrate from this precipitate was concentrated to about 25 c. c. and was then tested for creatinine by means of picric acid and sodium hydroxide. It may be said that many compounds, such as levulinic acid, tyrosine, pentose sugars, gallic acid, etc., which might be in the extract of plants, give the red color reaction with picric acid and sodium hydroxide, the red changing to yellow on adding acetic acid, so that this reaction was taken merely as a suggestion that creatinine was present in the water in which the seedlings were growing. The alcohol solution, which gave the color test, such as creatinine would give if present, was neutralized and brought to dryness, and was then treated with boiling absolute alcohol and filtered. The filtrate was again brought to dryness and the process of taking up with absolute alcohol and drying was repeated several times. The final slightly sirupy residue was treated with zinc chloride and sodium acetate in the usual manner and was put in a desiccator. In a few days stars, radiating clusters of needles, and rosettes of creatinine zinc chloride appeared. To make a further test the mass containing the crystals was boiled with freshly prepared lead hydroxide and filtered. The filtrate, concentrated to a small volume, gave Jaffé's test for creatinine, and also Salkowski's test with the formation of Prussian blue. The original nonacidified solution, when strongly concentrated, likewise gave Salkowski's and Jaffé's tests for creatinine. The amount of creatinine in the water was, however, very small.

The water in which the seedlings were growing with merely the roots in contact with the water was next tested for creatinine. The water was changed every second day for 10 days. Each sample was concentrated as soon as collected and all were combined and brought to a small bulk in a vacuum drier. The concentrated solution was made slightly acid with hydrochloric acid and was then treated with four or five times its volume of 95 per cent alcohol. A slight flocculent precipitate formed. The filtrate was concentrated again in a vacuum to a small bulk and then gave positive results with Jaffé's and Salkowski's tests for creatinine. The solution was then brought to dryness either at room temperature or in the steam bath. The dry residue was taken up as far as possible with about 50 c. c. of absolute alcohol and the alcohol solution was brought to dryness. The residue was again taken up with alcohol and the process repeated as long as a residue insoluble in the alcohol was formed on drying. Finally the cold alcohol solution was concentrated to a small volume and zinc chloride and sodium acetate added in the customary way. In a few days typical stars and rosettes of the double salt of creatinine and zinc chloride appeared. Accordingly creatinine or some precursor of creatinine, such as creatine, must be in the water in which the roots were growing.

That most of the creatinine at times at least is not present as such in the culture water is shown by the fact that if the water without acidification be concentrated to a small volume in a vacuum, at a temperature between 50° and 60°, Jaffé's test is very slight and at times negative. By warming on the steam bath, especially in the presence of dilute hydrochloric acid, the creatine or other antecedent body is converted to creatinine.

Whether the presence of creatinine or creatine in the medium in which the plants are growing is to be attributed to the action of microorganisms on materials sloughed from the roots or to direct osmosis from the intact seed and roots is a question that is rather hard to settle definitely. The following experiment, however, shows that creatinine or creatine can pass from seeds by direct osmosis, and in the same way may pass through the roots in the normal growth of plants.

CREATININE IN THE WATER IN WHICH SEEDS HAD BEEN SOAKING.

One kilogram of carefully sorted wheat seeds was placed in a flask with 2 liters of distilled water and the flask was kept in an ice box at 5° to 6° C. for five days. The liquid, to the quantity of about 1,500 c. c., was then poured off the slightly swollen, but entirely ungerminated seeds. In the liquid was a medley of organic substances, among which a small amount of creatinine was detected, as the following test shows:

Five hundred cubic centimeters of the slightly turbid, yellowish solution poured from the seeds was concentrated on the steam bath. To the concentrated solution, which had become brownish in color, a few cubic centimeters of hydrochloric acid were added, and then several volumes of 95 per cent alcohol. A slight flocculent precipitate formed. The filtrate was concentrated on the steam bath and made neutral by means of dilute sodium hydroxide. The neutralized solution gave Jaffé's and Salkowski's tests for creatinine. The solution was then allowed to dry in air. The dry residue was taken up with water and treated with lead acetate. The filtrate was freed from lead and was then brought to dryness on the steam bath. The dry residue was treated with absolute alcohol and the alcoholic solution again brought to dryness. The process of taking up with alcohol and drying was repeated until a residue was secured which was entirely soluble in absolute alcohol. The sirupy residue was treated with zinc chloride and sodium acetate and was placed in a desiccator. In about a week crystals of creatinine zinc chloride made their appearance in the brownish sirupy mixture. Boiled with lead hydroxide and filtered, the concentrated solution gave a good Jaffé test. On evaporating to dryness and taking up with absolute alcohol a solution was obtained which on concentrating and adding zinc chloride and sodium acetate gave the typical rosettes of creatinine zinc chloride. The creatinine must have come from the ungerminated seeds either as creatinine or as creatine or some other antecedent body which readily changes to creatinine.

CREATININE IN VEGETABLE MATERIALS.

WHEAT SEEDLINGS.

About 5,000 wheat seedlings, 9 to 11 days old, were ground and extracted for several hours with boiling alcohol. The hot alcohol was poured off and pressed out of the pulp and allowed to cool. The solution filtered through filter paper was concentrated to a small volume in a vacuum. The concentrated solution was filtered and treated with lead acetate to free it from coloring matter, etc. The fairly colorless filtrate was freed from lead by hydrogen sulphide. The filtrate from the lead sulphide was then concentrated to a small volume. The concentrated solution gave Jaffé's test, i. e., a red color with picric acid and sodium hydroxide, which was discharged on adding excess of alkali, and also on acidifying. Accordingly, zinc chloride and sodium acetate were added to the solution. In the course of several days creatinine zinc chloride appeared in the mass, in the form of stars, crenated hexagonals, needle clusters, and rosettes. Treated with lead hydroxide in the customary manner, a solution was obtained which gave Jaffé's and Salkowski's tests for creatinine.

WHEAT SEEDS.

A pound of wheat seeds was crushed and extracted with cold water. The turbid solution was concentrated and filtered free of the precipitate which formed on boiling. Several volumes of 95 per cent alcohol were added to the solution and the mixture was filtered. The filtrate was freed from alcohol by distillation, and the residue from the distillate was further concentrated. This residue, which gave Jaffé's test for creatinine, was brought almost to dryness on the steam bath, and was then treated with a small volume of 95 per cent alcohol. The alcohol solution was brought to dryness, and the process of taking up with alcohol and drying was repeated several times. Finally, to the slightly brownish sirup soluble in cold alcohol, zinc chloride and sodium acetate were added. Typical crystals of the double salt of creatinine zinc chloride formed in the course of several days in the desiccator. By adding water to the mass much of the sirup dissolved and was poured off. The creatinine zinc chloride was left behind and showed on drying in a desiccator as practically colorless stars and rosettes. (See Pl. I, fig. 5.)

The double salt of creatinine zinc chloride was obtained also from the direct alcoholic extract of ground wheat seeds. The ground wheat seeds were extracted for several hours in a Soxhlet extraction apparatus. The hot alcohol extract was brought to dryness, taken up with a little cold water, filtered, and concentrated almost to dryness. The residue was then treated with absolute alcohol, and the alcohol soluble portion after being brought almost to dryness was treated with zinc chloride and sodium acetate. In a few days hexagonals, stars, and rosettes of needles were apparent under the microscope.

WHEAT BRAN.

Wheat bran was extracted in a Soxhlet apparatus with 95 per cent alcohol. The extract gave Jaffé's test for creatinine. The alcohol was evaporated off and the residue was treated with cold water and filtered. The filtrate was treated with lead acetate to remove coloring matter, etc. The filtrate from the lead precipitate was freed from lead by means of hydrogen sulphide and the practically colorless filtrate was brought to dryness on the steam bath. The residue was then treated with absolute alcohol. The alcohol was again brought to dryness, etc., until the residue was all soluble in absolute alcohol. The addition of zinc chloride and sodium acetate gave rosettes of creatinine zinc chloride.

This experiment was repeated, using a large amount of bran. The sirupy mass containing the creatinine zinc chloride was placed on a porous plate and treated with alcohol and water until white. The residue on the plate was dissolved in boiling water and the solution was filtered. The filtrate was brought to dryness on the steam bath in a weighed porcelain dish. To the weighed residue nitric acid was then added and the solution was brought to dryness and carefully heated in a free flame until the nitric acid was all driven off. The residue was weighed as zinc oxide. The first weighing gave 22.6 per cent ZnO. On reheating, this was reduced to 21.8, which thereafter remained practically constant. Creatinine zinc chloride requires 22.4 per cent of ZnO.

WHEAT STRAW.

In alcoholic extracts of wheat straw practically no creatinine could be detected by the creatinine zinc chloride method. If the extracts, however, after being freed from coloring matter by lead acetate and from lead by hydrogen sulphide, were slightly acidified and boiled a fair amount of creatinine zinc chloride could be obtained. Apparently creatinine does not exist as such in the wheat straw while its congener creatine, or other antecedent body, does exist therein

WHEAT PROTEIN.

On boiling a water extract of ground wheat seeds a heavy precipitate formed. This precipitate, which gave protein color reactions, was washed with water, dilute hydrochloric acid, and alcohol until the washings on neutralizing and concentrating gave no tests for creatinine with picric acid and sodium hydroxide. The protein material was then boiled for 30 minutes with 3 per cent hydrochloric acid. From the filtrate, neutralized and concentrated and taken up with absolute alcohol, a solution was obtained which gave Jaffé's reaction and also crystals of creatinine zinc chloride on treating with zinc chloride and sodium acetate. Since the washings from the protein material also gave creatinine on heating with hydrochloric acid, the protein undoubtedly contained creatine.

Though there is some possibility that creatine and creatinine can be formed from the protein molecule or less complex nitrogen containing compounds, the origin of creatine and creatinine in the plant tissue is still an unsettled question.

Whatever is the origin of creatinine it exists in the wheat seed and in the wheat seedlings and is left more or less in the medium in which the seeds have germinated and the seedlings have grown.

RYE SEEDS.

Rye seeds ground to a coarse powder were extracted with hot 95 per cent alcohol. On cooling, the solution was filtered. The clear filtrate gave a strong Jaffé's test. Accordingly, it was concentrated to a very small volume and was tested for creatinine by zinc chloride and sodium acetate. The double salt of creatinine zinc chloride speedily formed in the mixture.

CLOVER AND ALFALFA SEEDS.

Alcohol extracts of clover and alfalfa seeds gave a strong creatinine color reaction with Jaffé's test. Since the alcohol extracts on cooling became somewhat turbid and also contained some coloring matter, water was added and the alcohol was driven off on the steam bath. To the water extract, lead acetate was added as long as a precipitate formed. The filtrate was freed from lead by hydrogen sulphide. The lead-free solution, brought almost to dryness on the steam bath, was treated with a small quantity of 95 per cent alcohol and filtered. The alcoholic solution was brought to dryness and the residue was treated with absolute alcohol. Finally, the part soluble in the absolute alcohol was concentrated to a small volume and was treated with zinc chloride and sodium acetate in the usual way. Creatinine zinc chloride in small quantities formed, both in the case of the clover extract and the alfalfa extract. Plate I, figure 6, shows the crystals of creatinine zinc chloride in the clover extract.

COWPEA PLANTS.

Creatinine was found in a similar way in the alcohol extract of young cowpeas, as shown in the previous section of this bulletin, and in mature cowpea plants.

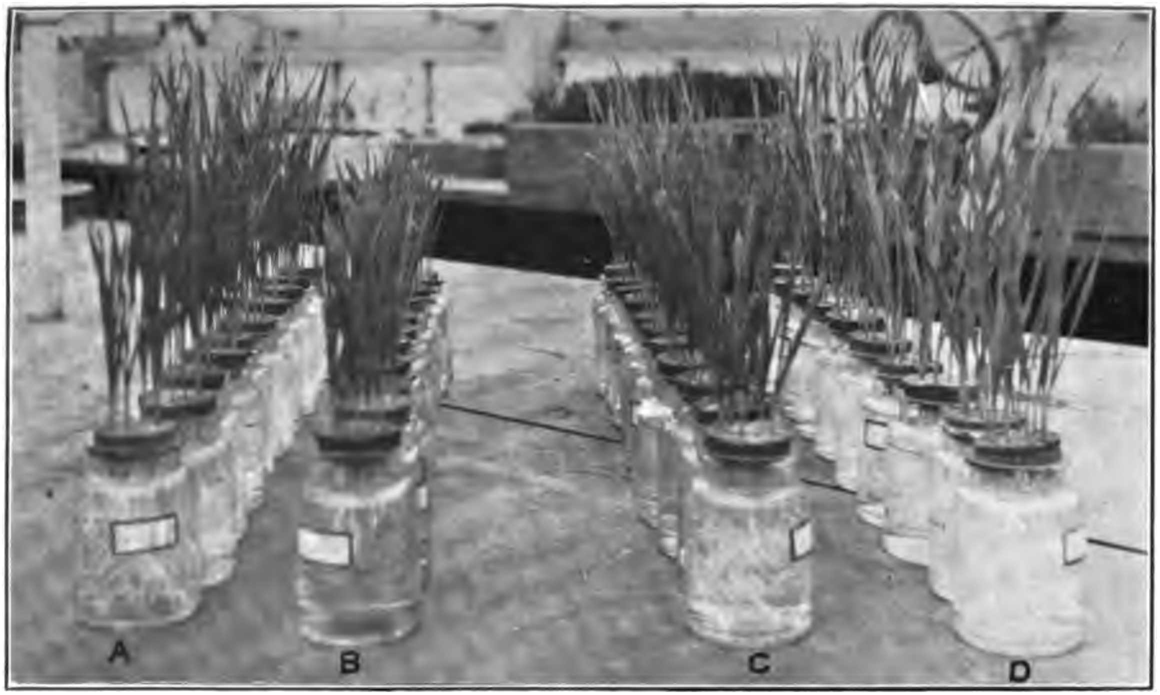
POTATO TUBERS.

Potato tubers were ground to a fine pulp and the pulp was extracted with a liter of boiling alcohol. The filtered alcoholic extract was brought to dryness and the dry residue was taken up with cold water. The water solution was then treated with lead acetate and filtered. The filtrate was freed from lead and was concentrated to a small volume. The concentrated solution gave Jaffé's and Salkowski's tests for creatinine. The solution was brought to dryness and the residue taken up with absolute alcohol. To the absolute alcohol solution concentrated to a few cubic centimeters zinc chloride and sodium acetate were added. In the course of three or four days a few crystals of creatinine zinc chloride appeared in the mixture.

SUMMARY.

Of samples of the same soil planted and unplanted kept side by side in the greenhouse, the planted soils gave larger amounts of creatinine. It would seem that the increase in the amount of creatinine was connected in some way with plant growth. Creatinine was also found in the water in which wheat seedlings had grown. The presence of creatinine in plants has not been previously reported. Various plants were tested for creatinine and its presence definitely ascertained. It was found in wheat seeds, wheat seedlings, and wheat bran, in rye, clover, alfalfa, cowpeas, and potatoes. If, as is suggested by several investigators, creatinine in the animal arises as the result of the breaking up of albumen, then it seems reasonable to expect that creatinine would be found in practically all plants.

Creatinine and creatine exist in vegetable matter to a slight degree. Though the amount of these compounds present is small it is worthy of attention, since by the decay of plants and by direct cell sloughing or even by osmosis the creatinine and creatine are left in water and soil where they exercise an effect on subsequent plant growth. Creatinine seems to persist for a considerable time in soils and may indeed increase in the soil by accumulation. Since both creatine and creatinine have a favorable effect on plant growth, their presence in plants and in the medium in which plants grow has considerable bearing on soil fertility.



WHEAT PLANTS GROWING IN CULTURE SOLUTIONS, WITH AND WITHOUT CREATININE, CONTAINING NO NITRATE, AND 8 PARTS PER MILLION OF NH_3 AS NITRATE.

Series A. Culture solutions, composed of a fertilizer mixture, containing 8 parts per million NH_3 as nitrate. Series B. Culture solutions, composed of a fertilizer mixture, containing no nitrate, without creatinine. Series C. Culture solutions, composed of a fertilizer mixture, containing no nitrate, with creatinine. Series D. Culture solutions, composed of a fertilizer mixture containing 8 parts per million of nitrate, with creatinine.

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EFFECT OF CREATININE ON GROWTH AND ABSORPTION.

By J. J. SKINNER,
Scientist in Fertility Investigations.

In the first paper in this bulletin are reported the results of an investigation showing the presence in soils of creatinine, a nitrogenous, organic compound. In the second paper its occurrence in plants and in cropped soils is shown. The present paper embodies a series of experiments on the influence of creatinine on crops. The results of this investigation showing the effect of creatinine, it is believed, throw much light on the action of organic manures in soils, and the influence of soil organic matter on productivity.

METHOD USED.

In studying the effect of creatinine on crops, wheat seedlings were grown in aqueous culture solutions containing the ordinary fertilizer salts, calcium acid phosphate, sodium nitrate, and potassium sulphate. Some of the cultures contained calcium acid phosphate only, some sodium nitrate only, and some potassium sulphate only. Other solutions were composed of mixtures of two salts, sodium nitrate and calcium acid phosphate, sodium nitrate and potassium sulphate, and calcium acid phosphate and potassium sulphate. Still other solutions had all three constituents in various proportions. The concentration of all the solutions was 80 parts per million of the fertilizer ingredients, P_2O_5, NH_3, and K_2O. In cultures containing only one fertilizer salt, for instance calcium acid phosphate, the concentration was 80 parts per million of P_2O_5. If two salts were present, for instance calcium acid phosphate and sodium nitrate, the concentration was 80 parts per million of $P_2O_5+NH_3$. If all three salts were present, the concentration was 80 parts per million of $P_2O_5+NH_3+K_2O$. The ratios of these constituents varied in 10 per cent stages. In all, there were 66 different cultures of nutrient solutions. Two sets of cultures were prepared; to one set were added merely the nutrient salts, to a similar set 50 parts per million of creatinine in each culture, in addition to the nutrient salts. The culture solutions were contained in wide-mouth bottles, holding 250 c. c., and 10 wheat seedlings grown in each culture, in a manner similar to that described in Bureau of Soils Bulletin 70. The culture solutions were changed every three days, four changes being made in the course of the experiment. The solutions were analyzed for nitrates immediately after each change. The phosphate and potassium were determined on a composite solution of the four changes. Observations on the development of the plants were made during the experiment and photographs were taken. When the plants had grown for 12 days the green weight was recorded.

EFFECT OF CREATININE ON GROWTH.

Two sets of cultures composed of the fertilizer salts, calcium acid phosphate, sodium nitrate, and potassium sulphate in varying proportions, used singly and in combinations of two and three, were prepared and young wheat seedlings were grown in them from March 3 to March 15. To one set of cultures only the nutrient salts were added, to the second set 50 parts per million of creatinine were added to each culture. Every three days the solutions were changed and analyzed.

When the plants had grown for several days it was noticeable that the creatinine cultures were better developed, having broader leaves and longer and better developed roots. This was more noticeable in some of the fertilizer mixtures than in others.

The total growth made in the 66 cultures of nutrient salts without creatinine, designated as normal or control cultures, was 166.7 grams as against 181.2 grams in the case of the 66 cultures with 50 parts per million of creatinine. Putting the normal at 100, the latter becomes 109, or an increase of 9 per cent, as an average of the 66 cultures. The effect was much more pronounced in those fertilizer combinations containing no nitrogen and those low in nitrogen.

GROWTH IN CULTURES CONTAINING NO NITRATE, WITH AND WITHOUT CREATININE.

Table I gives the growth of two sets of cultures composed of mixtures of phosphate and potash, varying in 10 per cent stages, there being no nitrate in the solutions, the concentration being 80 parts per million of $P_2O_5+K_2O$ in each culture. To one set of cultures was added 50 parts per million of creatinine. In the fourth column are given the green weights of the cultures without creatinine, and in the last column are given the weights of the cultures with creatinine. It is apparent from these figures that the creatinine has caused a considerable increase in growth. This is true in each of the 11 cultures. For instance, in culture No. 3, which has 16 parts per million of phosphate and 64 parts per million of potash, the growth without creatinine was 1.950 grams and with 50 parts per million of creatinine it was 2.100 grams. Culture No. 6, which is composed of equal parts of phosphate and potash, produced 1.558 grams green weight when creatinine was absent and 2.408 grams when the creatinine was present in the solution. The growth in culture No. 9, which is composed of 64 parts per million of phosphate and 16 parts per million of potash, was 1.444 grams without creatinine and 2.220 grams with creatinine.

TABLE I.—*Effect of creatinine on growth in cultures containing no nitrate.*

No.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5.	NH_3.	K_2O.	Without creatinine.	With creatinine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	0	80	1.400	1.576
2	8	0	72	1.470	2.200
3	16	0	64	1.950	2.100
4	24	0	56	1.527	2.000
5	32	0	48	1.490	2.200
6	40	0	40	1.558	2.408
7	48	0	32	1.795	2.328
8	56	0	24	1.540	2.400
9	64	0	16	1.444	2.220
10	72	0	8	1.400	2.100
11	80	0	0	1.100	1.150

The total growth of the 11 cultures, without creatinine, composed of mixtures of phosphate and potash was 16.674 grams against 22.682 grams for the cultures with creatinine. This is an increase of 36 per cent in the creatinine cultures.

The effect of creatinine in cultures with no nitrate is shown in Plate II. Cultures marked with the same number, for instance 1 and 1*c*, have similar fertilizer ratios. The cultures marked with numbers alone have no creatinine, the numbers with the letter *c* have 50 parts per million of creatinine. Culture No. 1 is composed of potash only, 80 parts per million; No. 2 has 72 parts per million of potash and 8 parts per million of phosphate; No. 3 has 64 parts per million of potash and 16 parts per million of phosphate; No. 4 has 56 parts per million of potash and 24 parts per million of phosphate; No. 5 has 48 parts per million of potash and 32 parts per million of phosphate; No. 6 has 40 parts per million of potash and 40 parts per million of phosphate; No. 7 has 32 parts per million of potash and 48 parts per million of phosphate; No. 8 has 24 parts per million of potash and 56 parts per million of phosphate; No. 9 has 16 parts per million of potash and 64 parts per million of phosphate; No. 10 has 8 parts per million of potash and 72 parts per million of phosphate; and No. 11 is composed of phosphate only, 80 parts per million.

As shown in the photograph, the plants in each culture containing creatinine, no matter what the proportion of potash and phosphate, is larger than the plants grown in a similar solution without the creatinine. The increased growth is noticeable in the roots as well as in the tops. The tops in each case are broader and taller and the roots are larger and better branched.

CREATININE IN CULTURES CONTAINING EIGHT PARTS PER MILLION NH_3 AS NITRATE.

Since creatinine was very beneficial in cultures containing no nitrate it is interesting to observe its effect in cultures which contain a small amount of nitrate. Table II gives the result of the effect of creatinine on growth in culture solutions composed of eight parts per million of NH_3 as nitrate and varying amounts of phosphate and potash, the total concentration of each solution being 80 parts per million of P_2O_5, NH_3, and K_2O. By comparing the figures in the second and third columns it is seen that the growth with creatinine, given in the last column, is larger than the growth without creatinine, given in the fifth column. The difference, however, is not near so great as in solutions containing no nitrate, presented in Table I. The total green weight of the cultures composed of fertilizer mixtures containing 8 parts per million of NH_3 without creatinine was 24.071 grams against 28.117 grams in the cultures with creatinine, an increase of 17 per cent. In the cultures with no nitrate creatinine produced an increase of 36 per cent.

TABLE II.—*Effect of creatinine on growth in culture solutions composed of fertilizer mixtures, containing 8 parts per million of NH_3, as nitrate.*

No.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5.	NH_3.	K_2O.	Without creatinine.	With creatinine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	8	72	1.820	2.190
2	8	8	64	2.470	3.100
3	16	8	56	2.748	3.250
4	24	8	48	2.907	3.420
5	32	8	40	2.670	2.450
6	40	8	32	2.928	3.258
7	48	8	24	2.526	3.340
8	56	8	16	2.600	3.000
9	64	8	8	2.048	2.359
10	72	8	0	1.354	1.750

CREATININE IN CULTURES WITH LARGER AMOUNTS OF NITRATE.

It has been shown that creatinine was very beneficial in cultures which contained no nitrate. In a group of cultures, composed of mixtures of phosphate and potash in different proportions, creatinine increased the growth 36 per cent. It has also been pointed out that the beneficial effect of creatinine was not so great in cultures containing a small amount of nitrogen. In the group of cultures composed of mixtures of potash, phosphate, and 8 parts per million of NH_3 as nitrate creatinine increased the growth only 17 per cent.

In Table III are given the results of growth in cultures with and without creatinine, composed of mixtures of phosphate, potash, and nitrate. The proportion of phosphate and potash vary in the different cultures, but each solution has 16 parts per million of NH_3 as nitrate. The green weights of the creatinine cultures, given in the last column of the table, are slightly larger than the control cultures shown in the fourth column. The total green weight of the cultures without creatinine was 25.516 grams against 27.573 grams for the cultures with creatinine, an increase of 8 per cent.

TABLE III.—*Effect of creatinine in cultures containing 16 parts per million of NH_3 as nitrate.*

No.	Fertilizer ingredients in culture solution.			Green weight of cultures.	
	P_2O_5.	NH_3.	K_2O.	Without creatinine.	With creatinine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	16	64	2.200	2.570
2	8	16	56	3.280	3.720
3	16	16	48	3.400	3.500
4	24	16	40	3.097	3.702
5	32	16	32	3.250	3.250
6	40	16	24	3.228	3.300
7	48	16	16	2.975	3.240
8	56	16	8	2.626	2.551
9	64	16	0	1.440	1.740

In other cultures composed of the three fertilizer ingredients, P_2O_5, NH_3, and K_2O, but containing 24 parts per million NH_3 as nitrate, creatinine only increased growth 2 per cent. Its effect in cultures composed of fertilizer mixtures having more than 24 parts per million of NH_3 as nitrate was uncertain. In some cases there was a slight increase in growth and in others there was a slight decrease. However, in all cases with large amounts of nitrate the growth was practically the same in the normal and creatinine cultures.

Before discussing further the effect of creatinine it will be necessary to show the effect which nitrates have on the growth of plants in mixtures of the other two fertilizer ingredients, potash and phosphate. In work previously published[1] it was shown that the better growth occurred in the normal cultures, when the three fertilizer elements P_2O_5, NH_3, and K_2O were present, and was best in mixtures which contained approximately equal amounts of NH_3 and K_2O and a small amount of P_2O_5, about 16 parts per million. The growth in the cultures containing the three constituents was much greater than in cultures containing only two constituents. This was especially marked when nitrate was not in the composition. In illustration of this the average growth of a number of cultures, composed of mixtures of phosphate and potash, in amounts of 80 parts per million of $P_2O_5 + K_2O$, was 1.000 gram against 3.155 grams as the average growth of cultures composed of mixtures of these two ingredients, with an addition of only 8 parts per million of NH_3 as nitrate, the total concentration of nutrients being the same. In a second experiment conducted in a similar manner, but at a later date, the average growth in the cultures composed of mixtures of phosphate and potash was 0.878 gram and the average growth in cultures consisting of mixtures of the three ingredients, 8 parts per million of the mixture being NH_3, was 2.107 grams.

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[1] Schreiner, O., and Skinner, J. J. Some Effects of a Harmful Organic Soil Constituent. Bul. 70, Bureau of Soils, U. S. Dept. of Agr., 1910.

In the present experiment the growth in the normal cultures composed of varying proportions of phosphate and potash, compared with the growth in mixtures of these two ingredients, with 8 parts per million of NH_3 added, is given in Table IV.

TABLE IV.—*Showing the growth of cultures, composed of fertilizer mixtures containing no nitrate, and 8 parts per million of NH_3 as nitrate; without creatinine.*

No.	Fertilizer ingredients in culture solution.			Green weight of cultures.	
	P_2O_5.	NH_3.	K_2O.	No nitrogen.	With nitrogen.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	0	80	1.400	....
2	0	8	72	....	1.820
3	8	0	72	1.470	....
4	8	8	64	....	2.470
5	16	0	64	1.950	....
6	16	8	56	....	2.748
7	24	0	56	1.527	....
8	24	8	48	....	2.907
9	32	0	48	1.490	....
10	32	8	40	....	2.670
11	40	0	40	1.558	....
12	40	8	32	....	2.928
13	48	0	32	1.795	....
14	48	8	24	....	2.526
15	56	0	24	1.540	....
16	56	8	16	....	2.600
17	64	0	16	1.444	....
18	64	8	8	....	2.048
19	72	0	8	1.400	....
20	72	8	0	....	1.354
21	80	0	0	1.100	....

The growth of culture No. 11, for instance, composed of 40 parts per million of P_2O_5 and 40 parts per million K_2O, is 1.558 grams against 2.670 grams for culture No. 10, which has 32 parts per million of P_2O_5, 40 parts per million K_2O, and 8 parts per million NH_3, or 2.928 grams for culture No. 12, which has 40 parts per million of P_2O_5, 32 parts per million of K_2O, and 8 parts per million of NH_3. By a close examination of the figures in this table it is seen that the growth in the mixtures of phosphate and potash is smaller than in cultures composed of mixtures of the three ingredients, containing 8 parts per million of NH_3 as nitrate. The average growth of the cultures without nitrate is 1.516 grams against 2.407 grams with 8 parts per million of NH_3 in the fertilizer mixture. Putting the growth of the cultures without nitrate at 100, the relative growth of the cultures with nitrate becomes 159, or an increase of 59 per cent.

In Table V are given the green weights of cultures with creatinine in the solution, similar to the results discussed above with the normal cultures. With 50 parts per million of creatinine in the solution the cultures containing no nitrate produced better growth than the corresponding cultures without creatinine shown in Table IV. The difference between the two last columns is not as marked in the creatinine set as in the normal set. For instance, culture No. 11, containing 40 parts per million each of phosphate and potash, produced 2.408 grams green weight against 2.450 grams for culture No. 10, which has 32 parts per million of phosphate, 40 parts per million of potash, and 8 parts per million of NH_3 as nitrate, and 3.258 grams for culture No. 12, which has 40 parts per million of phosphate, 32 parts per million of potash, and 8 parts per million of NH_3 as nitrate. The average growth of the cultures without nitrate is 2.062 grams against 2.812 grams for each culture having 8 parts per million of NH_3 as nitrate in the fertilizer mixture. If the growth of the cultures without nitrate is put at 100, the growth with nitrate in the fertilizer mixture becomes 136, or an increase of 36 per cent.

TABLE V.—*Growth of cultures composed of fertilizer mixtures containing no nitrate, and 8 parts per million of NH_3 as nitrate; with creatinine.*

No.	Fertilizer ingredients in culture solution.			Green weight of cultures.	
	P_2O_5.	NH_3.	K_2O.	No nitrogen.	With nitrogen.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	0	80	1.576	
2	0	8	72		2.190
3	8	0	72	2.200	
4	8	8	64		3.100
5	16	0	64	2.100	
6	16	8	56		3.250
7	24	0	56	2.000	
8	24	8	48		3.420
9	32	0	48	2.200	
10	32	8	40		2.450
11	40	0	40	2.408	
12	40	8	32		3.258
13	48	0	32	2.328	
14	48	8	24		3.340
15	56	0	24	2.400	
16	56	8	16		3.000
17	64	0	16	2.220	
18	64	8	8		2.359
19	72	0	8	2.100	
20	72	8	0		1.750
21	80	0	0	1.150	

In the control set of cultures without creatinine, presented in Table IV, the relative growth in solutions with nitrogen was 59 per cent greater than the growth in the cultures having no nitrogen in the fertilizer mixture. In the cultures with creatinine there was a difference of only 36 per cent in growth between the no-nitrate and the nitrate cultures. This might be taken to indicate that the creatinine replaced the efficiency of nitrate in producing plant growth.

Plate III shows the effect of creatinine with and without nitrate. As seen in the photograph, there is a large difference between the control cultures having a small amount of nitrate (series A) and those without nitrate (series B). The no-nitrate plants have small tops and poorly developed roots, while the nitrate plants have large tops and well branched roots. Series C, creatinine cultures without nitrate, compared with series D, creatinine cultures with nitrate, shows that this difference is not so great as in the case of the normal cultures with and without nitrate.

The effect of creatinine in cultures containing no nitrate is well shown by comparing series B with series C. Series A compared with series D shows that creatinine does not produce so great an additional effect when nitrogen as nitrate is in the culture.

INFLUENCE OF CREATININE ON ABSORPTION OF FERTILIZER SALTS.

The foregoing discussion has shown clearly the influence of creatinine on growth and its effect in cultures containing no nitrate. There remains to be discussed the effect of the creatinine on the removal of nutrients from the solution during the growth of the plant.

Mention has already been made of the fact that the concentration differences produced by the growth of the plants in the various cultures was determined by making an analysis for nitrate at the termination of every three-day change, and of the phosphate and potassium on a composite of the solutions from the four changes. It is thus possible to compare the results obtained under the so-called normal conditions without the creatinine and under the conditions where 50 parts per million of creatinine were present in the solution.

The sum total of P_2O_5, NH_3, and K_2O removed from solution by the growing plants in the cultures containing all three of these constituents was 1,684 milligrams under the normal conditions and 1,584 milligrams in the creatinine set. The figures show the total of plant nutrients removed to be slightly less in the creatinine set, although the green weight in this set was 9 per cent greater than in the normal set. The examination of the results for the three constituents separately, as given below, shows that the phosphate and potash absorption were slightly greater than normal, as is demanded by the larger growth, whereas the nitrate removal is considerably less than in the normal set.

Phosphate.—The phosphate in the cultures was determined by the method described on page 59 of Bulletin 70, Bureau of Soils. The amount of phosphate stated as P_2O_5 removed from the total number of solutions during the experiment was 364 milligrams for the normal cultures and 383 milligrams for the cultures containing creatinine, a difference of 19 milligrams in favor of the creatinine cultures.

Potassium.—The potassium was determined on a composite of the four changes by a method previously described.[1] The amount of potash stated as K_2O removed by the plants in the total number of cultures was 760 milligrams in the case of the normal cultures and 778 milligrams for the cultures with creatinine. As with the phosphate, the creatinine cultures removed a little more potash than the normal cultures, there being a difference of 18 milligrams in favor of the creatinine set.

Nitrates.—The solutions were analyzed for nitrates at the end of each three-day change, similar to the methods described in Bulletin 70, Bureau of Soils. The total amount of nitrogen stated as NH_3 removed from the total number of solutions during the course of the experiment was 560 milligrams for the normal cultures and 423 milligrams for the creatinine cultures. The creatinine cultures, although making a larger growth, used 137 milligrams less nitrate.

EFFECT OF CREATINE ON GROWTH.

Experiments in nutrient cultures with creatine have been conducted similar to those with creatinine. Creatine is closely related chemically to creatinine. Both probably occur in soils, manures, and green crops, a discussion of which is given in the two other papers in this bulletin.

The action of creatine on growth was determined by growing wheat seedlings in nutrient solutions of calcium acid phosphate, sodium nitrate, and potassium sulphate, similar to the method described earlier in this paper. The concentration of the solution was 80 parts per million of $P_2O_5+NH_3+K_2O$. The plants grew from April 22 to May 4. Notes were taken during the period of growth, and the green weight recorded at the end of the experiment. The culture solutions were changed every three days and the solutions analyzed for nitrate, phosphate, and potash.

After the plants had grown for several days it was apparent that the effect of creatine was very similar to that of creatinine. The leaves were broader and further developed than the control cultures. The roots were longer and better branched. The plants growing in creatine cultures which contained phosphate and potash but no nitrogen were a great deal larger than similar cultures without creatine. Like the creatinine, when a small amount of nitrate was in the fertilizer mixture the beneficial effect of creatine was not so marked, and in the presence of a larger amount of nitrate creatine had no additional effect.

The total green weight of 66 cultures, containing the fertilizer salts only—that is, the normal set—was 174.4 grams, against 186.8 grams for the 66 cultures containing 50 parts per million of creatine in addition to the fertilizer salts. This is an increase for the creatine cultures of 8 per cent over the normal cultures.

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[1] Schreiner, O., and Failyer, G. H. Colorimetric, Turbidity, and Titration Methods Used in Soil Investigations. Bul. 31, Bureau of Soils, U. S. Dept. Agr. (1906).

Table VI shows the effect of creatine on growth in a number of cultures containing varying amounts of phosphate and potash, but no nitrate, the amount of total fertilizer ingredient in each culture being 80 parts per million. From an examination of the table it is apparent that the growth of each of the creatine cultures, given in the last column, is considerably larger than the growth of the cultures without creatine, given in the fifth column. Culture No. 3, which has 16 parts per million of P_2O_5 and 64 parts per million of K_2O, produced 2.130 grams green weight with creatine and 1.558 grams without creatine. Culture No. 6, which has equal amounts of P_2O_5 and K_2O, produced 2.400 grams green weight with creatine and 1.5 grams without this substance. Culture No. 9, which has 64 parts per million of P_2O_5 and 16 parts per million of K_2O, produced 2.450 grams green weight with creatine and 1.600 grams without creatine. The total green weight of the cultures without creatine was 16.2 grams against 23.3 grams for the cultures with creatine, an increase of 44 per cent.

TABLE VI.—*Effect of creatine on growth in cultures containing no nitrate.*

No.	Fertilizer ingredients in culture solution.			Green weight of cultures.	
	P_2O_5.	NH_3.	K_2O.	Without creatine.	With creatine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	0	80	1.329	1.709
2	8	0	72	1.420	1.948
3	16	0	64	1.558	2.130
4	24	0	56	1.579	2.370
5	32	0	48	1.528	2.470
6	40	0	40	1.500	2.400
7	48	0	32	1.670	2.270
8	56	0	24	1.628	2.420
9	64	0	16	1.600	2.450
10	72	0	8	1.428	2.070
11	80	0	0	.978	1.090

In Table VII are given the green weights of plants grown in cultures with and without creatine, containing 8 parts per million of NH_3 as nitrate and varying amounts of P_2O_5 and K_2O, the total constituents being 80 parts per million of $P_2O_5+NH_3+K_2O$. These figures show that the creatine cultures, given in the last column, are somewhat larger than the cultures without creatine, given in the fifth column, but the difference is not near so large as in the cultures containing no nitrate given in Table VI. The total growth of the cultures without creatine was 26.4 grams against 29.4 grams for the cultures with creatine, an increase of only 11 per cent in favor of the creatine cultures. There was a difference of 44 per cent in favor of the creatine cultures, in the case of the solutions which contained no nitrate.

TABLE VII.—*Effect of creatine on growth in cultures containing 8 parts per million of NH_3 as nitrate.*

No.	Fertilizer ingredients in culture solution.			Green weight of cultures.	
	P_2O_5.	NH_3.	K_2O.	Without creatine.	With creatine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
1	0	8	72	2.299	2.459
2	8	8	64	2.940	3.200
3	16	8	56	2.700	3.350
4	24	8	48	2.920	3.400
5	32	8	40	3.050	3.070
6	40	8	32	3.150	3.309
7	48	8	24	3.220	3.350
8	56	8	16	2.500	2.854
9	64	8	8	2.222	2.800
10	72	8	0	1.400	7.600

The growth in cultures which contained varying amounts of phosphate and potash and 16 parts per million of NH_3 as nitrate was only 3 per cent greater with creatine than without creatine. In solutions containing 24 parts per million of NH_3 as nitrate the increased growth with creatine was 6 per cent, and in solutions containing 32 parts per million NH_3 as nitrate the increased growth was 4 per cent. In solutions containing higher amounts of nitrate the creatine had no additional effect. Thus it appears that the effect of creatine in replacing the effect of nitrate in producing growth is very similar to that of creatinine.

It is also interesting to note the effect of creatine on the removal of salts by the plants, and the similarity between the action of creatine and creatinine in this respect. It will be remembered that in the creatinine cultures the removal of phosphate and potash was slightly greater in the creatinine cultures than in the normal cultures, but a great deal less nitrate disappeared from solution in the creatinine than in the normal cultures.

In the creatine experiment the removal of total P_2O_5, NH_3, and K_2O by plants in the control cultures was 1,978.3 milligrams, against 1,854.5 milligrams for the creatine cultures. The control cultures removed 471.0 milligrams of phosphate, stated as P_2O_5, and the creatine cultures 474.4 milligrams. In the case of potash the control cultures removed 769.4 milligrams of K_2O against 767.4 milligrams for the creatine cultures. The removal of both phosphate and potash was practically the same in the control and creatine cultures. The disappearance of nitrate was much less in the creatine than in the control cultures. The control cultures removed 737.7 milligrams, against 612.7 milligrams for the creatine cultures, a difference of 125 milligrams.

The influence of the creatine as regards the removal of P_2O_5, NH_3, and K_2O is very similar to that shown by creatinine, and it again appears that this substance as well as the creatinine can replace nitrate in its effects on plant growth.

SUMMARY.

Creatinine and creatine have beneficial effects on plant growth.

Plants grown in solution cultures containing only potash and phosphate show greatly increased growth when creatinine or creatine is added.

When large amounts of nitrate are present in the culture solutions, creatinine or creatine produce no appreciable effect on the growth.

Plants growing in cultures, whether low or high in nitrate, showed a greatly diminished absorption of this ingredient when creatinine or creatine was present, whereas the removal of potash and phosphate was practically normal.

It appears, therefore, that creatinine and creatine can replace the effect of nitrate in plant growth.

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Issued March 28, 1912.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN NO. 84.
MILTON WHITNEY, Chief.

MODIFICATION OF THE METHOD OF MECHANICAL SOIL ANALYSIS.

BY

C. C. FLETCHER AND H. BRYAN.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., November 11, 1911.

SIR: I have the honor to transmit the manuscript of an article entitled "Modification of the Method of Mechanical Soil Analysis," by Messrs. C. C. Fletcher and H. Bryan, of this office. The article is accompanied by detailed working drawings showing the construction of improved apparatus used in the Bureau of Soils in making soil analyses. The information given should be of value to other soil investigators, and I therefore recommend its publication as Bulletin No. 84 of this bureau.

Respectfully,
MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

19243°—Bull. 84—12

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MODIFICATION OF THE METHOD OF MECHANICAL SOIL ANALYSIS.

INTRODUCTION.

The mechanical analysis of the soil, as carried out in the Bureau of Soils, has been devised as an expedient method of obtaining a quantitative statement for the classification of soils on a physical basis. There exists a close relationship between the mechanical composition and most of the physical properties of soils, although the exact nature of the relationship is not yet satisfactorily known. Many attempts have been made to classify soils upon the basis of some physical property, but to measure any physical property of soils without regard to the mechanical composition would disregard those relations of most importance in the practical management of soils. The physical properties of a soil are dependent upon the structure of the soil as well as upon the mechanical composition. The organic matter present influences both composition and structure. Hence we have a number of dependent variables of whose relations to one another we yet know very little. But the mechanical composition of any particular soil remains reasonably constant, so that it has been adopted as a basis for classification until the relationship existing between mechanical composition and the physical properties of the soil have become better known. The classification of soils on this basis is of agricultural value, as certain obvious characteristics attach to clays, loams, sands, etc., as classes.

In the mechanical analysis the soil is divided into a number of different grades of particles, whose dimensions lie between definite limits, and the percentage by weight of each of these grades is determined. In general, the basic methods used in mechanical analysis are separation of different size particles by sifting in the case of the larger particles, and by sedimentation (usually in water) in case of the smaller ones. Various successful modifications have been devised, based on these methods.

Mechanical analysis may be of service in other fields than in the classification of soils. Any industry in which a substance is to be reduced to a given degree of fineness may find the method described useful. Graphite, limestone, fertilizers, etc., may be separated by this method.

LIMITS OF MECHANICAL GRADES.

The names and sizes for the several separates which have been adopted by the Bureau of Soils are:

	Millimeters.
Fine gravel	2 -1
Coarse sand	1.0 -0.5
Medium sand	0.5 -0.25
Fine sand	0.25 -0.1
Very fine sand	0.1 -0.05
Silt	0.5 -0.005
Clay	0.005-9

This system of grouping the soil particles is purely arbitrary, and the particles are seldom separated naturally and easily into grades. The more grades into which a soil is correctly divided the better the idea of the value and behavior of the soil obtained, but the work and time required for separation is also greatly increased; especially is this true in making a large number of grades of the finer particles. The system used in the Bureau of Soils has sufficient divisions to meet every ordinary requirement, without unduly lengthening the time of analysis.

SCOPE OF WORK DONE BY THE BUREAU OF SOILS.

At the present time the collection of soil samples in the bureau numbers over 20,000, a majority of which have been subjected to mechanical analysis. Nearly 2,000 are being added annually. In order to perform the work quickly and accurately special apparatus is necessary, and the following equipment has been found to answer the purpose. Although part of the apparatus is found in every laboratory, everything required for the mechanical analysis of soils will be discussed for the benefit of persons wishing to install a complete laboratory for this particular purpose. A detailed description, with drawings of the parts of the shaking machine, the sieves, and the centrifuge, will be found at the end of this bulletin.

EQUIPMENT AND APPARATUS.

SHAKING MACHINE.

The shaking machine (Pl. I) consists of a carriage holding six trays supplied with places for eight bottles each. The carriage runs on a V-shaped cast-iron track and is driven by a one-fourth horsepower motor. The motor is connected with the carriage by two gears and an eccentric shaft. The small gear is a 12-tooth one, made of fiber and attached to the shaft of the motor; the other gear has 120 teeth, made of cast iron, and is attached to the end of the eccentric shaft. Connecting the eccentric with the carriage is a shaft with split bearing. The shaft is not a solid rod, but is divided at its center. A plunger with a steel head works in a brass case, and on either side of the head is a spring of 15 pounds compression, used to lessen the recoil. The motor is controlled by a rheostat and has a speed of 1,000 revolutions per minute, which the gears bring down to 100 revolutions per minute.

CENTRIFUGE.

For the separation of the finer particles some form of centrifuge is advisable; one run by any of the different forms of power may be used. When current is available, it is probably most satisfactory to use an electric motor. The centrifuge used in this laboratory has a one-fourth horsepower vertical-shaft electric motor, carrying a spider holding racks for eight tubes. The motor is started with a small rheostat, shown in the illustration at its right. Around the machine is a strong wooden guard, designed to minimize the danger to the operator from the breaking of glass tubes. The motor is attached by its base to the table, and the top of the machine is left open for convenience in filling or emptying the tubes, etc. A photograph of the centrifuge is shown in Plate II and detailed drawings at the end of the bulletin.

MICROSCOPE.

A compound microscope is used for determining the sizes of the soil particles. A very convenient instrument is supplied with an eyepiece micrometer so calibrated that one division equals 0.005 mm., the superior limit of the clay, and 10 divisions equal 0.05 mm., the upper limit of the silt particles. A high power objective is unnecessary, as the presence or absence of appreciable amounts of silt in the clay is easily discerned without it. An eyepiece micrometer calibrated to have two divisions equal 0.005 mm. is sometimes of special utility. With this arrangement it is possible to divide the clay into two portions with a lower limit of 0.0025 mm. for smallest particles. Ordinarily this is not done, as the greatly increased amount of time required for this separation is not justified by the additional information gained. It is usually considered advisable to depend entirely upon the coarse adjustment of the microscope, on account of the great gain in speed.

DISTILLED WATER UNDER PRESSURE.

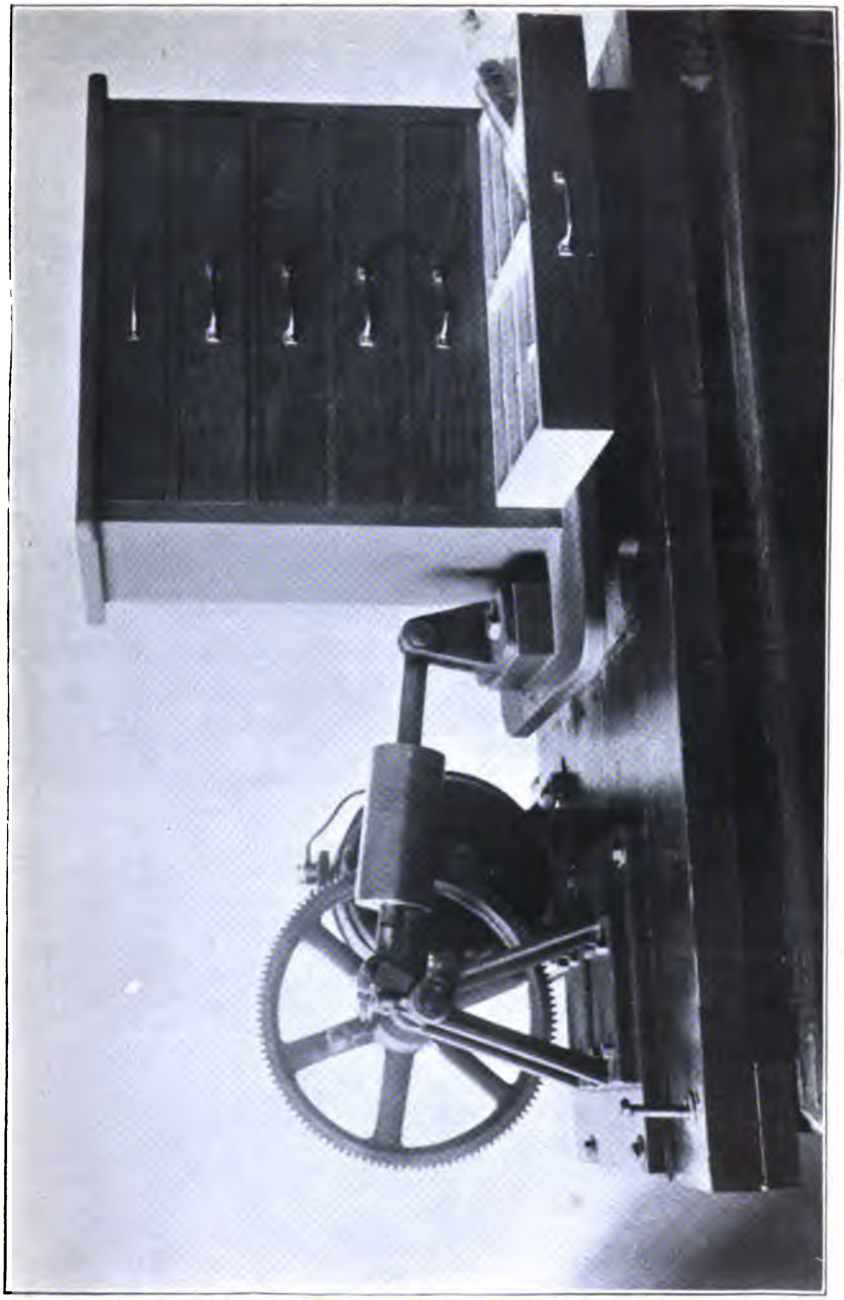
For many purposes a system of distilled water under pressure is of service. While it is possible to use ordinary filtered water in effecting separation, the amount of material in solution will be enough in many cases to impair the results. An analysis of the tap water at Washington, D. C., 5.2 liters (an amount often used on one sample during mechanical analysis) gave 0.425 grams solid material in solution, which is 8.5 per cent on a 5-gram sample of soil. Distilled water under pressure is used in stirring up the particles on the bottoms of the bottles and tubes. A jet of water from a capillary glass tube is directed upon the sediment and quickly brings the particles into suspension. A distilled-water system which has been found convenient for this purpose consists of a glass bottle of 12-liter capacity, with two attachments, one to suction for filling, and one to pressure to give the requisite force to the jet. A pressure of about 12 pounds to the square inch best meets the requirements. When a large pressure system is not available, a water or electric compressor will be found serviceable. It is not satisfactory to use an ordinary air pump and tank, because the pressure varies, and it is difficult to obtain a uniform suspension of the soil particles in the tubes and bottles. In the system used the water is carried through block tin pipes under the floor of the laboratory and up through the center of the table carrying the centrifuges. There it is distributed to each machine.

SAND SIEVES AND MECHANICAL SIEVE SHAKER.

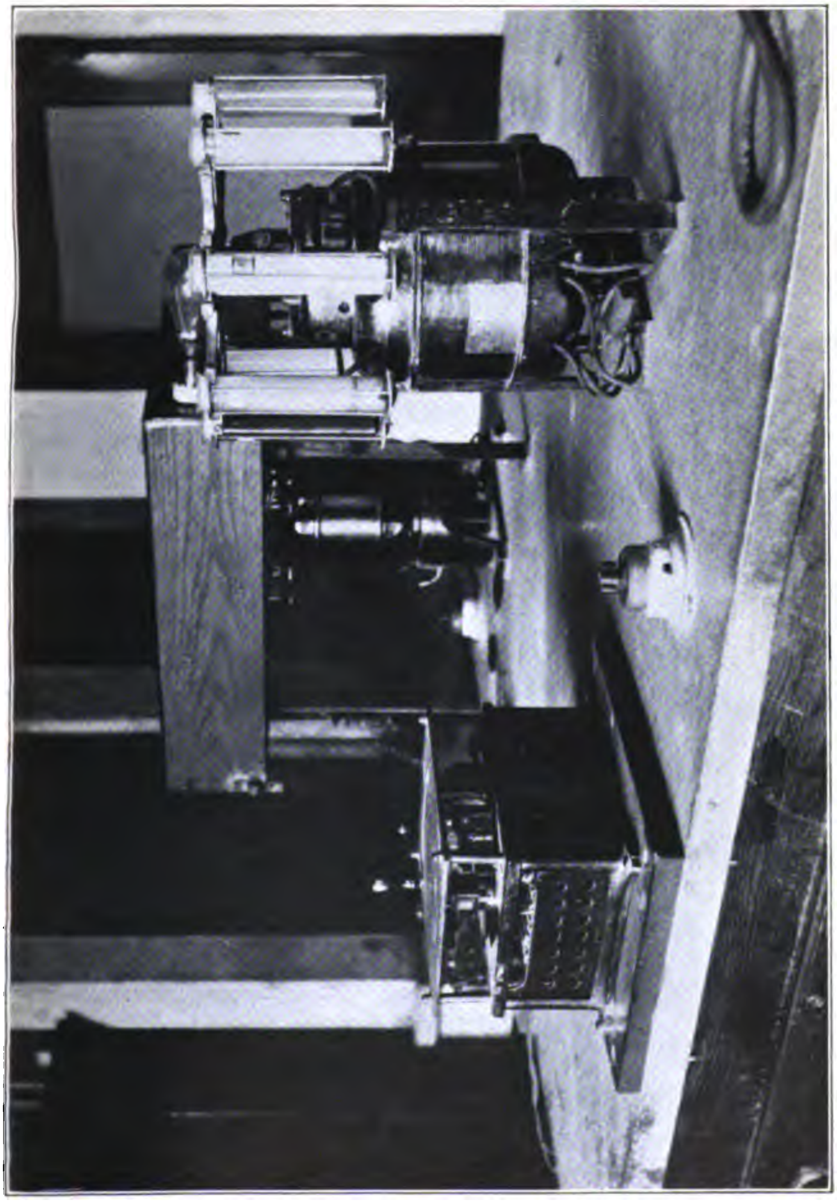
In separating the sands a nest of four sieves is used. The top and second sieves have brass plates with circular perforations of 1 and 0.5 mm. diameter, respectively, and the third and bottom ones have silk bolting cloth of No. 5XX and No. 13XX of double extra heavy quality, giving holes of practically 0.25 and 0.1 mm. diameter, respectively. The sieves are of brass, fitted one upon another, and have a closed base section to retain the very fine sand. The sections with silk bolting cloth have removable bottom rings, making it easy to replace worn cloth. The set of sieves is operated by a shaking machine, consisting of a small electric motor with an eccentric horizontal shaft. Clamps hold the sieves in position and a spring presses them down upon the shaft, which on rotating gives them a rapid movement in a vertical plane. Working drawings and photographs (Pl. II, figs. 1 and 2) of the sieves and shaker are given.

MISCELLANEOUS APPARATUS.

The steam bath used is of copper, supplied with holes in the top of a size to fit small platinum dishes. It is advantageous to have the number of holes some multiple of 8. There are also spaces at the back to hold porcelain cups. The holes are fitted with porcelain rings. An ordinary gas hot-plate is employed for drying down the clay water. For final drying electric ovens maintaining a uniform temperature of about 105° C. are used. Electrically heated ovens have an advantage in that they can be safely run overnight.



SHAKING MACHINE.



CENTRIFUGE.

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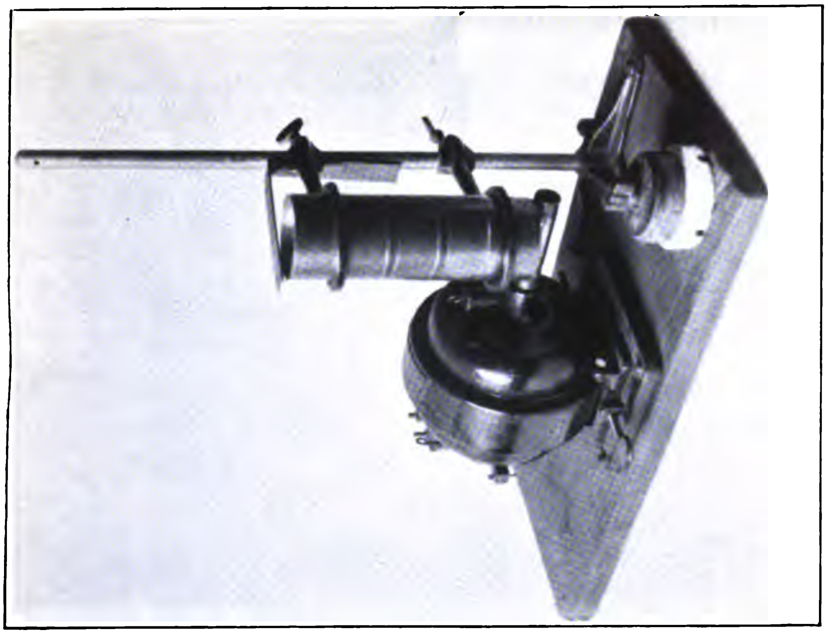

FIG. 2.—SHAKER IN POSITION FOR USE.

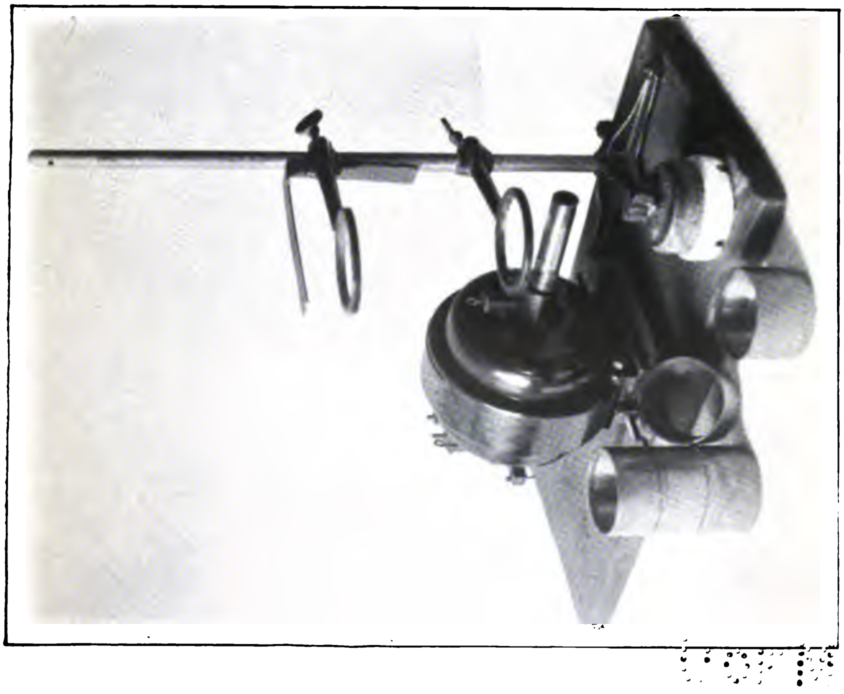

FIG. 1.—SAND SHAKER, SHOWING ARRANGEMENT OF SIEVES.

Two balances are employed—one with a 200-gram capacity for weighing sands and silts, and one with 500-gram capacity for the clay cups. Both the balances are sensitive to 0.001 gram, to which degree of accuracy all the weighings are carried out. The platinum dishes are small, round-bottomed ones, with a capacity of 50 c. c. The porcelain or enameled-ware cups and pitchers are the usual ones obtainable in any department store or camping supply house. The cups have a capacity of 550 c. c., width 9.5 centimeters, height 9 centimeters. The enameled-ware pitchers have a capacity of 2,500 c. c. The centrifuge tubes are 6¾ inches long, 1$\frac{3}{16}$ inches internal diameter, and $\frac{1}{16}$ inch thickness of wall; the bottoms are made extra thick to withstand pressure but not heat. The tubes are carefully annealed.

METHOD IN USE AT PRESENT.

SAMPLING.

The samples collected in the field are sent in canvas sacks to the laboratory and are preserved in the bureau's collection in glass jars. Coming through the mail the soil becomes more or less air-dry, and heavy clay soils are often in very hard lumps. In getting a subsample, the whole sample is thoroughly mixed with a spatula until as uniform an appearance as possible is obtained. Then a smaller sample is obtained by quartering. The soil remaining is returned to the glass jar. The subsample is then passed through a 2-millimeter sieve; any lumps present are crushed with a wooden rolling pin, care being used not to grind any gravel into sand or to break up the coarser particles into finer ones.

In some soils, where the gravel and sand are composed of very soft rock fragments and the clay is in hard lumps, it requires great care to avoid crushing the gravel and at the same time to get the true amount of clay. The fine earth—material less than 2 millimeters—is placed in small circular, flat-bottomed aluminum dishes and dried for at least two hours in the electric oven. It is then cooled in a desiccator, 5-gram samples weighed out, and put in 8-ounce sterilizer bottles with 2 ounces of water and a few cubic centimeters of ammonia. In weighing out the final samples material is taken from different parts of the subsample to insure uniformity as far as possible. The spatula should get each time a portion containing material from the bottom of the dish to the top. If this precaution is not taken the heavier particles will not be in their proper proportion, as they tend to settle to the bottom of the dish. While 5 drops of ammonia have been shown to be sufficient (Bulletin 24, p. 22), inasmuch as in the progress of analysis the soil is washed again and again, each time reducing the amount of ammonia, it has been found advisable to put in several cubic centimeters, and thus enough is left to keep the particles deflocculated until all the silt and clay are washed from the sand.

SHAKING.

The bottles containing the soil, water, and ammonia are put into trays and shaken by the mechanical shaking machine for at least seven hours. More time usually does no harm to the soil, but if left for too great a period of time the rubber stoppers may be eroded to an appreciable extent.

MAKING SEPARATIONS.

The eight bottles, numbered consecutively, are removed from the shaking machine and placed upright in the rack. The rubber stoppers are removed and examined for erosion; if the stoppers are badly eroded it may be necessary to repeat the analysis. Any soil material adhering to the stopper is washed back into the bottle with the jet, each of the eight soils is in turn brought into suspension by the use of the compressed water jet, and then sufficient time allowed for all the sands to settle. This time is determined by an examination with the microscope. In taking the sample for microscopic examination a small glass tube is employed and material is taken at a depth to which liquid will be removed by decanting. Thus, if 1 inch of material is to be left in the bottle, it is not necessary to take the material below that level. Usually if the contents of the eight bottles are stirred up in order, by the time the last bottle is reached the first is ready to decant. Liquid from bottle No. 1 is poured into centrifuge tube No. 1, etc., and when the tubes are filled the centrifuge is run until there are no silt particles left in suspension. This is determined with the microscope. If time is no object, every soil should be examined, but usually only the soil containing the most clay is tested and the time for the whole set gauged by that necessary for this soil. The clay suspension is poured from tube No. 1 into pitcher No. 1, from tube No. 2 to pitcher No. 2, etc., and the silt at the bottom of the tubes is brought into suspension by the use of the jet. After centrifuging again another microscopic examination is made to determine the absence of silt particles in suspension. The liquid is decanted as before. This process is continued until the separation is complete. As a rule, in making the earlier separations the larger particles are held up by smaller ones; consequently as the separation nears completion it is possible to reduce the time before decanting. This is done in the sand-silt separation by stirring up a smaller number of samples at a time, and in the silt-clay separation by reducing the time of centrifuging.

The length of time will vary with the soil and speed of the centrifuge. Thus clay soils are almost invariably more difficult to separate than sandy soils, both in duration of centrifuging and in the number of times run before the separation is complete. With the centrifuge used in the Bureau of Soils the time usually varies from 10 down to 5 minutes or less, the number of times depending on the type of soil. The length of time for the complete separation usually approximates two hours for a very sandy soil up to eight or more hours for clay soils. The analysis is finished when the silt and clay are removed from the sand and the clay is separated from the silt.

As a matter of fact, it is impossible to get absolutely clean separations. It is possible in the sand-silt separation to balance up the sand poured into the silt by leaving silt in the sand, similarly with the silt-clay separation. Another method of balancing errors is to pour off silt, and so arrange the time that the largest-sized silt particles go over without any sand, and call the determination complete when no more silt can be poured over without also pouring over sand. Similarly in the silt-clay separation, the centrifuge is run as long as any clay can be removed from the silt without pouring over silt. The determination is considered finished when it is not possible to get more clay without pouring over silt. When the separation is complete the sands are in sterilizer bottles, the silt in the centrifuge tubes, and the clay in the porcelain pitchers. The sands are transferred from the bottles to small platinum dishes, dried by the steam bath and electric oven and cooled in a desiccator. The total weight of the sands is determined, after which the separation into five grades is made with the set of sieves. The dried sands are placed in the top sieve of the set and the whole nest placed in position for shaking. Separation into five grades is usually effected by three minutes' shaking. Each of the sands or the residues in the sieves and bottom is weighed; the total weight should come within 10 milligrams of the initial weight. These five weights give the amounts of the five grades of sand in the soil sample. The silts are transferred from the tubes to platinum dishes, dried, cooled, and weighed similarly to the sands.

DETERMINATION OF THE CLAY CONTENT.

In the method of mechanical analysis of soils originally devised and used in the Bureau of Soils[1] the amount of clay was determined—after the coarser particles had been separated by centrifuging—by evaporating the clay-water to small bulk in enameled-ware saucepans, transferring it to platinum, carrying completely to dryness, and weighing the residue. This method was found undesirable on account of the excessive time required for the evaporation, and because many dust particles and fragments cracked from the lining of the saucepans were incorporated with the clay and weighed with it. In addition, the transfer from saucepans to platinum required much time and trouble and offered possibilities of loss. To avoid these difficulties, and especially to increase the rapidity of the work, it was decided to abandon the final transfer to platinum, and to complete the evaporation in enameled-ware dishes and weigh the clay in them without transfer. For convenience in weighing and to decrease the likelihood of entry of dust, the saucepans were discarded and much smaller enameled-ware cups were adopted. The cups have a capacity of about 300 c. c. and weigh about 180 grams each. This method has the disadvantage of requiring a much heavier balance, but the determinations seem none the less accurate, and a great saving of time has been effected. When speed is especially important the method may be still further shortened in the case of routine analyses by abandoning altogether the direct determination of clay and obtaining its percentage by difference. The error thus introduced is probably no greater than that involved in the centrifugal (or other) separation of the clay from the silt. The errors in both cases are generally within the limits of variation which may be expected between different samples of the same soil.

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[1] See Bulletin No. 24, Bureau of Soils, U. S. Dept. Agr. (1904).

In 100 consecutive analyses taken at random from the recent files of the Bureau of Soils the variations between the percentage of clay as directly determined and those obtained by difference range between 0 and 2.28 per cent. In two cases the variation is over 2 per cent; in three cases, between 2 per cent and 1.5 per cent; and in six cases between 1.5 per cent and 1 per cent. In all other cases the variations were less than 1 per cent.

It is probable that in many cases the determination by difference is the more accurate, as all errors due to access of dust or to loss of clay suspension are thus avoided. Errors due to a not impossible change in the state of hydration of the clay are also eliminated. It is believed that in the vast majority of cases the method of determining clay by difference will be accurate within 1 per cent, and no greater accuracy is necessary or even desirable for purposes of soil classification. The saving of time is at least one-third, and this is well worth considering in routine laboratories where a large number of analyses are made. The direct determination must, of course, be retained for cases of special importance or where a check is necessary, and is probably also desirable for students and for small laboratories where a mechanical analysis is only made occasionally.

DIFFICULTIES ENCOUNTERED IN MECHANICAL ANALYSIS.

It is customary in making a mechanical analysis of a soil to disregard the organic matter, because, generally, it is distributed between the different separates, and the dry weight of organic matter in any one separate is not great. A high organic content makes a mechanical analysis of a soil difficult. No satisfactory method of removing the organic matter has been devised, as any process which will get rid of the organic matter will change the character of the mineral soil particles. It is possible to remove the organic material by ignition, but in the process water of combination in the clay is driven off. The method used is to let the organic matter remain in the soil, trusting that it will be evenly distributed and that there will not be enough to interfere with the value of the analysis. It is not possible to make an accurate mechanical analysis of a muck or peat soil, and, as a rule, it should not be attempted with soils of this character.

Soils which disintegrate during analysis are occasionally found. In such cases the judgment of the analyst must be relied upon. The best procedure is to make an approximate analysis as rapidly and as accurately as possible. During every analysis some of the soil goes into solution, and under the present system is estimated as clay, whether the clay is determined by direct weight or by difference. As probably the major portion of the soluble material is absorbed by the clay, and as the clay, being composed of finer particles, also goes into solution more rapidly than the other separates, it is more reasonable to estimate the soluble matter as clay than as silt.

In some cases flocculation persists after the addition of ammonia. This difficulty is overcome usually by additional shaking or varying the concentration of ammonia. In deflocculating materials other than soils other agents than ammonia may be employed; for example, tannic acid for graphite powder.

Micaceous soils present a special problem in mechanical analysis. The particles as thin plates remain in suspension much longer than their apparent size under the microscope would seem to justify. In all cases the separations are made by size and not by weight; so a particle which has two dimensions larger than the superior limit of one grade is counted in the grade above, even though its weight may be far less than many of the particles in the lower grade. In sifting to obtain the sands, anything which will go through the sieve is weighed where it finally rests, even though it may have one dimension very much greater than the superior limit of that grade, and to be consistent the same idea is followed out in using the micrometer in the microscope. Any particle which would go through an imaginary sieve with circular perforations of 0.05 mm. and be held by a sieve of 0.005 mm. is counted as silt, and any particle which would go through the latter sieve would be counted as clay. This method leaves less to the personal equation of the operator than any other system devised.

Possibly the soils which cause the most trouble are those that contain a large percentage of particles near the limiting size between very fine sand and silt, or between silt and clay. Often soils are encountered where it is almost impossible to say whether a considerable percentage of the sample should be classified as silt or clay. It is either coarse clay or fine silt. When this condition occurs, the only feasible course is to run the centrifuge for a longer period than necessary to get all the silt particles deposited. Then by gradually reducing the time of centrifuging and running for a considerable number of times, only a small amount of clay is decanted each time. Finally, when the time comes to determine between the fine silt and the coarse clay particles, all the fine clay particles have been removed and the determination is rendered less difficult.

DETAILED DESCRIPTION OF APPARATUS.

MECHANICAL SIEVE SHAKER AND SAND SIEVES.

The mechanical sieve shaker (Pl. IV, sheet 1) consists of sieves arranged to vibrate rapidly. The vibration is effected by the use of a ⅛-horsepower electric motor *A* mounted on a wooden base. Connected to the horizontal shaft of the motor is an eccentric brass sleeve *B* 2½ inches long and ⅝ inch in diameter, with the center hole ⅛ inch off center. The set of sieves *C* is held on the eccentric by ring clamps *D*, with holes 2¼ inches in diameter, and standard *E* fastened to a wooden base. The sieves are forced down by the spring *F*. The power is controlled by switch *G*. The sand sieves *C* are $6\frac{3}{16}$ inches long and 2⅛ inches outside diameter. Each one of the upper four sections is 2⅛ inches outside diameter, 1⅛ inches long, and 2 inches inside diameter. The upper two are supplied with brass plates with circular perforations 1 and 0.5 millimeter diameter, respectively, and the two lower with silk bolting cloth of No. 5XX and No. 13XX, double-extra quality, having holes of practically 0.25 and 0.1 millimeter diameter, respectively. The sieves are of brass, fitted one within the other, and have a closed base section, 2⅛ inches outside diameter and $1\frac{3}{16}$ inches outside height; inside height, $1\frac{1}{16}$ inches. The brass perforated plates and the silk bolting cloth are held in position by accurately fitting removable rings $\frac{7}{16}$ inch long, 2 inches inside diameter, and 2⅛ inches outside diameter.

CENTRIFUGE.

The centrifuge (Pl. VII, sheet 4) consists of a ¼-horsepower vertical-shaft electric motor, carrying a spider holding rack for eight tubes. The motor *A* makes 900 revolutions per minute at highest speed, but lower speeds may be obtained by a rheostat control. The brass spider *B* is keyed to the shaft of the motor and held in place by a nut. The spider is 12¼ inches in diameter, ½ inch thick, and with hub 2 inches wide, 1¼ inches in diameter, and with a ⅝-inch hole. Attached to the spider by two steel screws *C* are eight baskets *D*, 6¼ inches long and 1¾ inches in diameter. These baskets consist of two brass plates; the top plate is 1¾ inches in diameter, ⅛ inch thick, and with a 1¼-inch hole. In use the hole in the bottom plate is covered with a felt pad. The plates are connected by three steel wires ⅛ inch in diameter and 6¼ inches long, riveted to the plate at each end.

SHAKING MACHINE.

The carriage *A* of the shaking machine (Pl. V, sheet 2, and Pl. VI, sheet 3) has the following greatest exterior dimensions: Length 30 inches, and height 19⅝ inches. The base is 30 inches long, 15 inches wide, and 1 inch thick. The top is 20 inches long, 12 inches wide, and 1 inch thick. The frame or body of the carriage is 17⅝ inches high, 10½ inches deep, the ends of ¾-inch material, and the partitions between the drawers of ½-inch lumber. The drawers *B* are 16½ inches long, 10¼ inches wide, and 2½ inches deep, outside measurement. The drawers are partitioned off into eight divisions, each division is 7⅝ inches long, $2\frac{7}{16}$ inches wide, and 2⅛ inches deep, inside measurement, giving sufficient space to hold one 8-ounce sterilizer bottle. The carriage is of oak wood, with the exception of the bottoms, and division of the drawers, which are of poplar.

The carriage runs on V-shaped cast-iron ways or tracks *C*, 20 inches long, 1⅛ inches wide and 1⅛ inches high. The portion of the track on which the carriage runs is 16 inches long; at each end the rim is slightly raised to make a pocket to catch excess of oil.

The machine is driven by an ordinary stock ¼-horsepower motor *D*, making 1,000 revolutions per minute, and controlled by a rheostat. The motor is connected with the carriage by two gears and an eccentric shaft *E*. The gear attached to the shaft of the motor is 12-toothed, 10-pitch, fiber, which is meshed with a 120-tooth, 10-pitch, cast-iron gear, attached to the eccentric shaft running in two cast-iron standards *N*. The base plate is 6 inches long and 3 inches wide. The height is 7 inches. The bearing for the shaft is 1½ inches in diameter and 1½ inches long, with a ¾-inch hole in it.

To obviate the danger of throwing the shaft out of alignment, the standards are bolted with ⅜-inch cap screws to a cast-iron base plate *O*, 12 inches long, 9 inches wide, and ⅝ inch thick. The base plate is attached to the wooden base by four lag screws, ½ inch in diameter. The machine is mounted on an oak board 45 inches long, 30 inches wide, and 1½ inches thick. The eccentric shaft *E* is made of steel, 8 inches length over all, ¾ inch diameter, and set off center 1½ inches. Connecting the eccentric with the carriage is the shaft *F*, 8 inches long, 1 inch in diameter, with a split head 2 inches in diameter and ½ inch thick. On the other end is a plunger with a steel head 2½ inches in diameter, ¾ inch wide, with a ¾-inch hole, which is held to the shaft *F* with a lock nut *P*, ½ inch thick, 1¼ inches in diameter, 16 threads, with ½-inch hole. This plunger works in a brass case *H* 6 inches long, 3 inches outside diameter, and 2½ inches inside diameter. The head through which the shaft *F* works is brass, 2.575 inches in diameter, ¾ inch thick, with 1-inch hole, threaded on outside, 16 threads to the inch, to fit similar threads in the ¾ inch from the end of the inside of brass case *H*. The continuation of the shaft *Q* is attached to the end of the brass case on one end and to the cast-iron bearing *R* at the other end. The shaft *Q* is 5½ inches long with a 2½-inch face ½ inch long, and a body 3 inches long and 1 inch in diameter. The end working in *R* is ½ inch thick, 2 inches long, with ½-inch hole through the center. On both sides of the piston, inside the brass case, are springs *I*, length 3 inches, outside diameter 2⅜ inches, with about 15 pounds compression. Connecting the shaft *Q* and the carriage *A* is a cast-iron triangular block *R*, 6 inches long, 3 inches wide, and 4¼ inches high. The slot for *Q* is ⅝ inch wide. The block is connected with steel pin *S* and with carriage by two ⅜-inch lag screws.

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Issued November 23, 1912.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 85.
MILTON WHITNEY, Chief.

A STUDY OF THE SOILS OF THE UNITED STATES.

BY

GEORGE NELSON COFFEY,
Scientist in Soil Survey.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., February 16, 1912.

Sir: I have the honor to transmit herewith a report entitled "A Study of the Soils of the United States."

This report was written by Dr. George N. Coffey, as a thesis submitted in partial satisfaction of the requirements for the degree of doctor of philosophy at the George Washington University, before leaving the Department of Agriculture to take up the study of Ohio soils for the Ohio experiment station. In it Dr. Coffey has put together in orderly arrangement the accumulated results of his long service in the Bureau of Soils of this department. He entered the service in 1900, and during the 11 years of his connection with the bureau he held all the positions in the Soil Survey Division from the lowest to the highest. He did detailed mapping in the field for several years and in areas scattered widely over the country. As inspector of soil mapping in the field he had an opportunity to study a still wider range of soils and soil conditions than he had while engaged in detailed field work. His work as a member of the committee on soil correlation gave him further knowledge and experience in soil classification.

The Bureau of Soils at the present time groups soils on the basis of soil-forming processes and geographic conditions, substantially as shown on the soil province maps issued in connection with Bulletins 55 and 78. This primary grouping is thus based upon the origin and process of formation rather than upon the characteristics of the soils themselves.

In the detailed map of an area actually surveyed the soils are differentiated into types and series on the basis of the characteristics of the soil itself, regard being had always to the province or origin and process map. In this way only has it been found possible to avoid the difficulties which Dr. Coffey's map seems to show as inevitable in an attempt, at the present time and with our limited knowledge, to construct a general map based upon the characteristics of the soil itself. Nevertheless the report and map are presented for publication, as it is important that we may clearly see more than one of the many sides of the difficult problem of soil classification.

I recommend that it be published as Bulletin No. 85 of the series of this bureau. In publishing it, however, the Bureau of Soils does so for the purpose of offering it to the scientific world as a contribution to the subject, without indorsing the scheme of classification proposed and without accepting all the conclusions drawn from the facts cited.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A STUDY OF THE SOILS OF THE UNITED STATES.

INTRODUCTION.

No industry is so vital to the well-being of a nation as agriculture and nothing so vital to agriculture as the soil. From its treasury it has been estimated[1] that we drew last year (1909) more than $8,926,000,000, and its possibilities are as yet only partially realized. There are still in this country millions of acres which have never felt the plow, while those which are now under cultivation can, by the application of scientific principles, be made to produce many times the present value of their products. How to use and not abuse this great resource is the most important problem which faces the farmer of to-day—one worthy of the best efforts of our most profound and learned scientists; for upon its solution depends the future prosperity of the nation.

When Liebig presented the mineral theory of plant nutrition many thought that the problem of soil fertility had been fully and finally settled. This work gave a great stimulus to the study of the soil in the laboratory, while equally important field investigations were given little attention. Only within comparatively recent years has the importance of the study of the obvious field differences in soils been recognized and undertaken in a systematic manner, but enough has already been accomplished to show the value of this line of investigation. More than 800 different types, each possessed of definite and peculiar characteristics have already been discovered in the progress of the soil-survey work in the United States, although only a relatively small percentage of this country has been covered at the present time. The existence of such a great number of types calls attention to the need of a study of the differences which are here represented in order that their influence upon the growth of plants may be understood. That these variations do have a marked influence is becoming more and more evident as these investigations are pushed forward.

One great need in agricultural work to-day is the more general recognition of the individuality of soils; a fuller realization of the true meaning of soil differences. Much valuable time and money have been wasted trying to draw definite conclusions from experiments conducted upon entirely dissimilar soils. Many of the contradictory and seemingly inexplicable results obtained by different investigators, or even by the same investigator, are undoubtedly due to fundamental soil differences which would have been evident from a comparative field examination. Hilgard has said, "The history of plat experiments shows so common and unpardonable neglect on the part of experimenters to ascertain definitely the fundamental physical and chemical conditions, that their general unsatisfactoriness is easily accounted for on that score alone."[1] While a field study will not furnish all of this information, much of it can not be secured in any other manner.

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[1] Report of the Secretary of Agriculture, 1910, p. 7.

NOTE.—The author wishes to acknowledge his indebtedness to Dr. George P. Merrill for many helpful suggestions and kindly criticisms received during the preparation of this paper.

The failure to recognize that the results secured upon one type do not necessarily hold true for another is responsible, in some measure at least, for the distrust which farmers often show toward the work of scientific investigators, as well as for the unsettled and unsatisfactory condition of the great problem of soil fertility. A farmer is told that a certain method of cultivation, certain varieties of crops, certain kinds of fertilizers, will give the best results. He goes home and tries these, but the results are not what he expected. Why? Probably because the soil on his farm is entirely different from that upon which his adviser's experiments were conducted.

It is often possible to learn something of a man's opinion about a question by consulting his friends, but it is not safe to depend upon them entirely for information. He and he alone can give definite and positive knowledge in regard to what he thinks. So with soils. Each type must be questioned separately and individually. The answer given may then be safely recommended for a similar soil, but may not apply upon one of a different character. The classifying, mapping, and correlating of the soils of the country, as a fundamental basis for the study of all those problems in which the soil forms one of the limiting factors, thus becomes of the very greatest importance and will prove of inestimable value to the advancement of agriculture.

The old idea of soil investigation was to collect samples, examine them in the laboratory, and see what differences could there be determined; the newer idea is to study the characteristics and properties of soils in the field, classify them according to obvious differences, and, with this information in hand, use the laboratory as a means of ascertaining the cause of such variations as can not be determined in the field. This method of attacking soil problems is the reverse of the usual practice, but because of the great difficulty in duplicating field conditions, it is believed that a field examination should precede laboratory studies. The field observations can thus be used as a check upon laboratory investigation and as an aid in their interpretation. If this plan had been followed in the past, it would have prevented the publication of many erroneous conclusions deduced from laboratory studies alone. Field studies furnish "a safe and necessary anchor with which to keep the laboratory experimenter from being dashed against the rock of pure speculation."[1] The classifying and mapping of the various soil types, together with the study of the conditions and processes under which they have been formed, will furnish essential and invaluable data for the conduct of laboratory investigations. Nature's great laboratory is in the field, and a study of her methods can not fail to offer many valuable suggestions, and in some cases, is the only means of solving her problems. It is through a combination of field and laboratory investigations that an understanding of this extremely complex body—the soil—can be reached.

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[1] Agricultural Science, vol. 6, p. 327.

Realizing this fact, it is the purpose of this paper to describe briefly the character of the soils in different parts of the United States as determined by extensive field observations and to give, some at least, of the reasons for the variation from one section to another. To furnish a clearer understanding of the subject matter a preliminary discussion of the distinctive characteristics of the soil, its principal constituents, the factors which determine the proportion of these constituents, and therefore its character, will be given. This will be followed with a brief discussion of the principles of soil classification. These principles will be applied and a general classification and description of the more important soils of the United States given.

NATURE AND ORIGIN OF THE SOIL.

DEFINITION.

The land surface of the earth is almost everywhere covered by a thin mantle of unconsolidated material. There are places along the shore, on steep mountain sides, or other situations exposed to excessive erosion, in river beds, and in regions of recent glacial or volcanic activity, where the bare, hard rock forms the surface, but such instances are not common occurrences and usually cover only very small areas, so that it may be said that the entire land surface consists of unconsolidated material. Although the horizontal distribution of this material is so very wide, its vertical range is relatively very small, and it really comprises only a thin veneer over the consolidated rock beneath.

Some writers, especially geologists, are inclined to use the term soil in its broadest sense to include all of this mantle, or regolith, as it has been termed by Merrill,[2] but the agricultural meaning is much more restricted. Although the soil consists largely of degenerated rock, not all unconsolidated rock can be considered as soil. This material must be acted upon by life in some form before it becomes a true soil. Until this action has taken place it is best to think of it as unconsolidated rock, although it may be readily converted into soil by the influence of organic agencies. The soil may, therefore, be considered as the superficial, unconsolidated mantle of disintegrated and more or less decomposed rock material, which, acted upon by organic agencies and mixed with varying amounts of organic matter, may furnish conditions necessary for the growth of plants. In this conception the soil is an independent, natural body, a bio-geological formation, differing essentially from the rock which underlies it, although closely related to it. It is the one great formation in which the organic and inorganic kingdoms meet and derives its distinctive character from this union.

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[1] Paper by H. J. Wheeler in Proceedings of American Society of Agronomy, vol. 1, p. 44.

[2] Rocks, Rock-Weathering and Soils, p. 299.

In this medium profound physical, chemical, and biological changes are constantly taking place. As the influence of life is greater near the surface, this portion of the regolith usually shows its effect most markedly, and this fact has led to the popular designation of the first few inches, which have been darkened by organic matter, as "soil," while the underlying part is termed "subsoil." The line of demarcation represents the depth to which most of the roots of grasses and other small forms of vegetation have penetrated. Below this depth the influence of organic agencies markedly decreases and gradually diminishes until it is no longer evident, and the subsoil merges into the underlying rock. This distinction between soil and subsoil is one of undoubted practical importance. It is especially marked in the humid regions, while in the arid it is much less evident, owing to the existence of different climatic conditions and resultant soil processes. The term soil is thus used in a broad and in a restricted sense. Its exact meaning can usually be determined from the context, but whenever ambiguity might arise it is well to use a qualifying term, as surface soil.

CONSTITUENTS.

From the foregoing, then, the soil is seen to be composed of mineral and organic matter, the former usually predominating. In the case of peat and muck soils the organic matter may reach as high as 75 per cent by weight, or even more, but the average soil would probably show less than 3 or 4 per cent of the entire mass to be of organic origin. The inorganic portion, being thus so greatly in excess, determines very largely the properties of the soil.

INORGANIC.

The mineral matter of the soil varies in both physical nature and chemical composition. Physically the particles may differ in size, shape, weight, color, etc., while chemically they may be as varient as the rocks from which they have been derived through degeneration.

Physical composition.—From the physical standpoint the principal inorganic constituents of the soil are sand, silt, and clay, although there may also be present, as stones or gravel, larger pieces of the rocks. All mineral particles less than 2 mm. in diameter, but not smaller than 0.05 mm., are classed as sand.[1] This practically means that macroscopic particles will be included in this grade. Sand possesses practically no coherency, and its addition to a soil will therefore make it looser and more porous.

Silt includes particles within the limits 0.05 and 0.005 mm., too small to be seen readily with the naked eye. Pure silt possesses very little coherency and is of a floury or mealy nature. While it will not give plasticity to a soil, it causes it to be very much more retentive of moisture and less open and leachy than sand.

All particles less than 0.005 mm. are classed as clay.[2] To it are due some of the most important properties of the soil. Without it soils are so loose that they are easily driven about by the wind, and so porous and leachy as to be often almost or entirely unfit for useful culture. Plasticity and adhesiveness are to be attributed to it. No other inorganic constituent has nearly so marked an influence in determining the character of the soil. In other words, the addition of a certain percentage of clay will have a more pronounced effect upon the texture, for example, than the addition of a similar amount of any of the other grades. Its plasticity, its "retentiveness of moisture, as well as of gases and of solids dissolved in water, imparting these important properties to soils containing it," explain its great influence as a soil ingredient.

Since all of the fine earth is included in the above three classes, it follows that an increase or decrease in one grade must be accompanied by a corresponding decrease or increase in one or both of the other grades. The relative proportion of the particles of different sizes determines the texture, which is the most important physical property of the soil, while the arrangement of these particles constitutes the structure.

Chemical composition.—In chemical composition the inorganic matter varies according to the kind and relative proportion of the various minerals of which it is composed. Quartz or silica greatly predominates in nearly all soils, this oxid alone constituting, according to Clarke,[3] 59.89 per cent of the crust of the earth.

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[1] The sizes as used here and elsewhere in this paper are those adopted by the Bureau of Soils, U. S. Department of Agriculture.

[2] "Clay" is used in the strictly physical sense. It is clearly recognized, however, that the clay is not alike in all soils and that soils having the same percentage of particles of this size vary in plasticity and other properties, although all soils having more than one-third of this grade will be "heavy" or "clay" soils.

[3] U. S. Geol Survey, Prof. Paper No. 14, p. 108.

The mineralogical nature of the soil depends very largely upon the petrographic character of the rock from which it has been derived. There is always a tendency, however, for the more soluble and more easily decomposed minerals to be leached out in the change from rock to soil unless the processes are almost entirely mechanical. For this reason there is usually a relative increase in the proportion of difficultly soluble material like quartz. The contrast between the composition of the rock and the derivative soil is most pronounced in the case of the purer limestones, which are composed almost entirely of the relatively soluble mineral calcite ($CaCO_3$). While this fact causes soils to be more alike in chemical composition than the rocks from which they have been derived, still the character of the latter has a pronounced influence in determining the physical, chemical, and biological properties of the resultant soils.

Experiments have shown that there are 13 or 14 elements, or compounds of these elements, which participate in the normal growth of plants or are at least always present. These are potassium, sodium, calcium, magnesium, iron, manganese, phosphorus, sulphur, silicon, chlorin, carbon, hydrogen, oxygen, and nitrogen. Of these the first 10 are obtained from the mineral matter of the soil, the other 4 coming from the air, the soil water, or the organic matter. Since the discovery of these facts most of the efforts of chemical soil investigators have been directed toward determining the amount, especially the "available" amount, of these elements present in the soil, particularly potash (K_2O), phosphoric acid (P_2O_5), lime (CaO), and nitrogen (N), these being the constituents which were considered as liable to be deficient. For this reason, any statement in regard to chemical composition is almost necessarily restricted to these compounds.

In a recent publication Whitney[1] has brought together "the results of all the analyses, made in the United States by the 'acid-digestion' method[2] during the past 18 years so far as they have been found in the literature." The following table gives the average by States of the analyses contained in this publication:

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[1] A Study of Crop Yields and Soil Composition in Relation to Soil Productivity, by Milton Whitney, Bul. 57, Bureau of Soils, U. S. Dept. of Agr.

[2] The "official method" does not show whether the lime (CaO) exists in the form of silicate or carbonate. In the opinion of the author very little, if any, lime carbonate occurs in the surface soils of the humid regions, and the determination of lime by this method may be misleading, since it is the lime as carbonate which exerts the most important influence.

Average chemical composition of the soils of the United States by States.

State.	Number of samples.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Alabama	4	0.35	0.06	0.16	0.25
Arizona	22	.83	.13	2.79	1.83
Arkansas	6	.26	.08	.10	.14
California	115	.75	.15	1.90	1.61
Colorado	30	.62	.20	2.00	.64
Connecticut	1	.23	.22	.32	.78
District of Columbia	4	.42	.08	.39	.06
Florida	88	.03	.15	.31	.05
Georgia	2	.13	.09	.13	.15
Idaho	37	.61	.36	1.35	.98
Illinois	5	.38	.10	.61	.60
Indiana	13	.37	.28	.17	.18
Iowa	2	.35	.12	.99	.62
Kansas	7	.51	.11	1.07	.39
Kentucky	92	.35	.27	.18	.12
Louisiana	18	.51	.09	.44	.59
Maine	1	.14	.17	....	....
Maryland	14	.45	.15	.35	.16
Massachusetts	1	.15	.14	.53	.66
Michigan	40	1.06	.32	1.27	.55
Minnesota	163	.36	.23	1.16	.52
Mississippi	276	.31	.10	.80	.29
Missouri	8	1.45	.07	.54	.88
Montana	2	.74	.18	.92	1.01
Nebraska	15	.48	.28	1.15	.43
Nevada	48	.63	.32	4.34	1.50
New Hampshire	5	.93	.15	.70	.51
New Jersey	2	1.15	.77	.66	1.12
New York	16	.55	.10	.58	.74
North Carolina	2	.09	.04	.16	.03
North Dakota	25	.57	.27	1.97	.37
Ohio	57	.25	.13	.29	.39
Oklahoma	3	.52	.05	.72	.18
Oregon	136	.30	.25	.08	.60
Pennsylvania	24	.43	.13	.28	.54
Rhode Island	7	.15	.09	.54	.26
South Carolina	11	.13	.12	.10	.15
South Dakota	2	.38	.15	.69	.61
Tennessee	144	.28	.12	.20	.27
Texas	117	.41	.09	2.78	.45
Utah	55	.88	.20	5.66	.78
Virginia	2	.54	.23	.12	.09
Washington	104	.33	.12	1.29	.88
West Virginia	14	.53	.14	.16	....
Wisconsin	13	.65	.17	.96	.58
Wyoming	9	.63	.17	2.25	1.22

In general it will be noted that there are marked variations in chemical composition and that the soils of the arid to subhumid States show considerably larger percentages, especially of lime and magnesia, than those of the humid States, while those of the Southeastern States are usually low in all constituents.

Some peculiarities appear in this table which can probably be accounted for by a variation in the strength of the acid used, by the analyses having been made by different analysts, or by the samples not being representative of the principal soils in the State. For example, the average percentages for Michigan, with the possible exception of magnesium, are very much higher than the surrounding States, although there is no apparent reason why this should be so. The percentages in New Jersey are likewise high, but only two samples were analyzed, and these may represent soils derived from greensand marl.

In pushing this line of investigation other mineralogical and chemical studies have often been very largely neglected, the idea seeming to be that the only important chemical differences consist in a variation in the amount of plant food present, either in "available" or "unavailable" form. In the case of lime it has been clearly demonstrated that while it consists of two of the essential plant-food elements its importance does not depend upon this fact alone, but also upon the various effects which it has upon the physical, chemical, and biological activities which proceed in the soil. It has, therefore, both a direct and an indirect action upon the growth of plants. Because of these various and pronounced influences it is chemically the most important of the mineral soil constituents.

Since it has been definitely shown that the importance of lime is not due entirely or even largely to its satisfying one of the food requirements of plants, it seems very probable that other mineral ingredients, even those which are not considered as essential plant foods, may act in a similar manner, one of the most probable effects being an indirect action upon the higher plants through the medium of lower forms of life.

It is probable that many secondary minerals are formed as a result of synthetic processes. Chemical changes are always taking place, old compounds are being broken down and new ones formed in order to bring about a more nearly stable condition. Many of these changes and conditions are very imperfectly understood. It is certain, however, that differences in the mineralogical and chemical composition of the earthy material have a profound influence in determining the character of the soil and that these must be more clearly understood before definite knowledge of its nature can be secured.

ORGANIC.

While the proportion of organic material in most soils is relatively small, its influence upon the growth of plants is very pronounced. In the form known as humus[1] it is one of the three (lime and clay being the other two) most important soil constituents—one which may often be deficient, especially in the arid and timbered regions. The organic portion of soils, consisting of the remains of plant and animal life, exists in various forms and stages of decomposition, about which very little is definitely known.[2]

The condition in which the organic matter exists is probably of as great, or even greater, significance than the actual quantity. Both the condition and the quantity are dependent largely upon the character of the inorganic portion. The most beneficial form is that of humus, which gives the dark color so characteristic in the black prairie regions. Just exactly what form this is can not now be stated definitely, but that it is different in some way from that either in swamp or timbered soils is not to be questioned. In the swamp soils, which may be as black as the prairie, the dark color is caused by partially decomposed organic matter, due to arrested decomposition as a result of poor aeration, and rapidly disappears under drainage and cultivation. In the prairie soils decomposition has gone much further and the organic product is in a much more stable form. This is shown by the fact that little change in color takes place even after many years of cultivation. In the timbered regions the processes of decomposition are unlike either of the above, and a different character of organic matter is found. This is of a lighter color and in a less humified condition, so that an equal amount does not give as dark a shade as in the prairie soils.

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[1] This term is used rather indefinitely in agricultural literature, sometimes as the equivalent of organic matter. In this paper it will be used as above to denote the black organic matter which gives the dark color to the prairie soils.

[2] See Bulletins Nos. 49, 53, 70, 74, 77, 80, and 83, Bureau of Soils, U. S. Dept. of Agr.

These differences are due to the unlike conditions under which decomposition has taken place, or failed to take place, and will be discussed further in connection with the processes of soil formation.

FACTORS WHICH DETERMINE THE CHARACTER OF THE SOIL.

Since the soil varies so much as regards both its inorganic and organic constituents, marked differences in character must necessarily result from the almost indefinite number of combinations which may be found. All these differences, however, may be traced to two sets of factors: First, the character of the rock or material from which the soil has been derived; and, second, the processes or agencies by means of which this material has been changed from mere rock or rock débris into a medium suitable for the growth of plants. The former has to do with soil-forming material, the latter with soil-forming agencies. To these two groups of factors are to be attributed the numerous variations in soil conditions found over various parts of the earth.

The importance of distinguishing between these two groups of factors can not be too strongly emphasized. The tendency in the past has been to stress the former to the neglect of the latter, and this has resulted in classifying together soils of very dissimilar character, simply because they were derived from the same rocks, or from rocks which have been formed in the same manner. The influence of the rock might be likened to heredity and that of the processes of formation to environment. The character of the soil can no more be determined from a study of the rock alone than that of a man from a study of his ancestors. It is well, therefore, to consider the processes that are concerned in soil formation and the effects which they have upon its character separately from the influences of the material upon which they are acting and the variations due to this latter cause.[1]

SOIL-FORMING AGENCIES.

Many agencies and processes are concerned in the changing of rocks to soils, but most of these vary with the moisture and temperature, so that these two may be considered as having the greatest influence in determining its character.

Moisture.—The most important agency of soil formation is moisture, not only because of the direct influence which it exerts, but also because nearly all the processes of soil formation vary with the rainfall. Water is nature's great solvent, and regions of heavy precipitation generally consist of lixiviated soils, the more soluble material having been leached out by the carbonated waters. For this reason soils of arid and humid regions are always markedly dissimilar, although they may be formed from identically the same rocks.

A compilation by Hilgard[2] of analyses of the soils of the humid and arid regions not derived from limestones gave the results in the following table:

Average chemical composition of soils of the humid and arid regions.

Region.	Insoluble residue.	Potash.	Soda.	Lime.	Magnesia.	Peroxid of iron.	Phosphoric acid.	Water and organic matter.	Humus.
Humid........	84.17	0.21	0.14	0.13	0.29	3.33	0.12	4.40	1.22
Arid...........	69.16	.67	.35	1.43	1.27	5.48	.16	5.15	1.03

On page 11 is given an average by States of a large number of chemical analyses. An average for the States situated principally in the arid, prairie, and timbered humid regions, respectively, gives the following results:

Average chemical composition of the soils of the arid, prairie, and timbered humid regions.

Region.	Number of Samples.	K_2O.	P_2O_5.	CaO.	MgO.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Arid..	318	0.71	0.21	2.65	1.20
Prairie..	215	.43	.18	1.09	.51
Timbered humid....................................	743	.37	.16	.41	.37

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[1] The purpose in this paper is not so much to go into a discussion of the exact nature of these processes, which has been well done by many writers, but rather to emphasize the differences in the soils which have resulted from variations in these processes.

[2] Soils, by E. W. Hilgard, p. 377.

While the percentages here depart considerably from those quoted from Hilgard they agree in showing a much larger percentage in the arid than in the humid soils.

In the Field Operations of the Bureau of Soils for 1901 are given the "soluble salts"[1] for all the samples of which mechanical analyses were made. An average of the analyses given here shows the following results:

Average percentage of soluble salts in the soils of the arid, prairie, and timbered humid regions.

Region.	Number samples.	Soluble salts.
		Per cent.
Arid	155	0.333
Prairie	12	.048
Timbered humid	200	.013

A mere glance at this table is sufficient to show the much greater amount of soluble material in the soils from the arid regions as compared with those from the humid. The number of samples of prairie soils is not sufficient to give anything like a true average, but shows that the percentage here is between that of the other two.

On pages 87 to 91 of this paper is given a mineralogical analysis of the sand and silt in a number of the most important soil series. An average of the series in the arid, prairie, and timbered humid sections gives the following percentages of minerals other than quartz:

Average percentages of minerals other than quartz in the soils of the arid, prairie, and timbered humid regions.

Region.	Number of samples.	Minerals other than quartz in the—	
		Sand.	Silt.
		Per cent.	*Per cent.*
Arid	30	37	39
Prairie	40	20	29
Timbered humid	160	8	12

This table brings out quite strikingly the difference in soils formed under humid and arid conditions and agrees with the others which show a much larger percentage of soluble matter in the latter than in the former. It shows, also, the more siliceous nature of the sands in the humid region. While other agencies or causes have been partly instrumental in bringing about this contrast in the soils of the two regions, there is no doubt that it is primarily due to differences in the amount of precipitation, the arid soils being much less leached than the humid.

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[1] The "'soluble salts' represent the amount of mineral matter, determined by the electrolytic method, calculated as sodium chloride, dissolved when the soil is mixed with 10 parts by weight of water and shaken for one hour at room temperature."

An unleached or calcareous condition, combined with a sufficient amount of moisture to give a luxuriant growth of vegetation is most favorable to the accumulation of a large percentage of humus. These conditions are found in the transition zone between the humid and the arid regions and here is located the great group of Dark-colored Prairie soils. Few differences in soils are comparable in importance to those between these black soils and the soils of the arid region on the one side and of the more humid on the other. This will be emphasized further when the subject of soil classification is taken up.

Moisture is essential for most of the chemical changes that take place in the degeneration of the rocks. Lack of moisture, therefore, causes a decrease in decomposition and a relative increase in disintegration so that the result is the predominance of mechanical agencies in all sections of deficient rainfall. Consequently, in an arid climate the soils are generally low in clay, while in a humid region a greater amount of decomposition has taken place and a larger number of fine particles have been formed, thus giving rise to soils of heavier texture.[1]

Water is also a very efficient agent of transportation, and in addition to the direct formation of the large group of alluvial soils, may also effect morphological changes by the displacement of the soil particles. By the washing out or down[2] of the finer particles very great changes in the texture may be brought about.

It is very common, therefore, to find marked contrasts in texture between the surface soil and subsoil in regions of heavy precipitation. This is especially pronounced where the material is made up of particles that vary much in size, while it is much less evident where the soil grains are almost uniform. For example, the sandy clays of the Lafayette formation give a very sandy surface soil, usually changing very abruptly into a sandy clay subsoil, while the loess, composed almost entirely of silt, shows very little difference in texture between the surface soil and subsoil. This is brought out very clearly by a comparison of the percentage of clay in the soils and subsoils of the two formations obtained by averaging a large number of mechanical analyses.

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[1] Of course, the actual amount of clay present will depend to a large extent upon the character of the rock, but the above statement will hold true for soils derived from similar rocks. If soils are derived from unconsolidated material the contrast will not be so marked.

[2] Most writers lay nearly all the emphasis upon the latter, but according to the author's observations the former is by far the more important.

Percentage of clay in the soils and subsoils of types derived from the Lafayette and Loess formations.

Formation.	Proportion of clay in--	
	Soil.	Subsoil.
	Per cent.	*Per cent.*
Lafayette	8	32
Loess	15	20

The carrying power of water increases as the sixth power of the velocity therefore any factor, like topography, that tends to increase or decrease the velocity will cause a variation in the amount of displacement that will take place. The effect of this is that on level areas the fine material is not removed very far below the surface. As the slope increases so does the depth until the velocity of the water becomes sufficient to carry even the coarser sands, in which case the entire surface material is removed and the heavier subsoil exposed. In this manner very marked variations in soil texture are brought about. The differences in the Orangeburg sand, sandy loam, and clay, which are derived principally from the red sandy clays of the Lafayette, are, for example, due to exactly these processes.

Attention has already been called to the very profound chemical differences which exist between soils in regions of light and of heavy rainfall. Others of almost equal importance, although affecting less extensive areas, may result from dissimilar drainage conditions. This is well illustrated upon the eastern shore of Maryland,[1] where three very distinct groups, or series, of soils have been formed as a result of different drainage conditions. Where good drainage is established the yellow-brown soils of the Sassafras series occur; where water stands practically all the year, the black Portsmouth soils are found; and where intermediate or alternate wet and dry conditions exist the white soils of the Elkton series have been developed.

In the case of the black soils the difference is due largely to an accumulation of organic matter under poor conditions of aeration. In the white soils[2] chemical changes in the mineral matter[3] have been induced, largely through the action of the so-called humus acids. According to Hilgard[4] these reduce "the ferric hydrate to ferrous salts, oxidizing away the humus, and accumulating in the form of inert concretions most or all of the lime, iron, and phosphoric acid of the soil mass." So profound are the changes which may be brought about that almost identical soils may be formed from very dissimilar material and vice versa.

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[1] See Soil Survey of Easton Area, Maryland, by H. H. Bennett and party, Field Operations, Bureau of Soils, 1907, p. 137.

[2] In addition to the Elkton soils just cited might be mentioned the Worsham sandy loam, formed from granites and gneisses, the Guthrie silt loam, derived from limestones, and the Waverly soils, consisting of recent alluvial deposits. Small areas of these white soils have also been seen in the Memphis silt loam, which is a typical Loess formation, while the Marion silt loam might also be considered as of this formation.

[3] Compare mineralogical composition of Sassafras and Elkton soils in the Table on p. 95.

[4] Soils, by E. W. Hilgard, p. 285.

An intermittent wet and dry condition will not give these white soils unless the underlying material is noncalcareous. If the soil contain considerable lime carbonate it will become darker instead of lighter in color, as the organic matter will be changed into humus. This peculiar variety of white soil is seldom found outside of the humid regions, because the conditions necessary to its formation do not exist elsewhere.

The principal effects of moisture upon soils as here emphasized are (1) to induce profound chemical changes (*a*) by leaching out the more soluble mineral matter, and (*b*) by differences in drainage; (2) to influence the amount and character of the organic matter (*a*) by arresting decomposition as in swamps, and (*b*) by small amount of leaching, causing it to assume the very stable form which gives the dark color to the soils of the prairie regions; and (3) to produce differences in the texture (*a*) by variation in decomposition, and (*b*) by mechanical displacement of the particles, especially the finer.

Temperature.—That heat expands and cold contracts is well known. Likewise the fact that different substances have different coefficients of expansion. Since rocks consist of mineral aggregates, each of which has its own ratio of expansion or contraction, changes in temperature will produce such strain upon the rocks as to aid very materially in their disintegration. This effect will be greatest where the diurnal or annual range of temperature is at a maximum. The former is found in desert regions and the latter in northern latitudes.

Since an increase in temperature also increases the solvent power of water, so that a warm, moist region is most favorable to decomposition, the mechanical processes of soil formation are relatively more pronounced in dry and in cold climates. This has an influence upon both the physical and chemical composition. It tends to give to the soils of the warm, humid regions (1) a larger amount of clay, because of the more thorough decomposition, which is essential to reduce the particles to the finest subdivisions, and (2) to cause them to be more thoroughly leached of their more soluble constituents. All other conditions being similar, a region of uniformly high temperature will have heavier (especially subsoils), more lixiviated soils, than a colder region of marked extremes in temperature.

Soils formed by the predominance of decomposition processes are characterized, as a rule, by brilliant, contrasting colorings, which are absent in cold or dry regions, unless they exist in the underlying formations. Red soils, which are almost entirely absent in the northern and arid portions of the United States, are very frequent in the southern, while in tropical regions red becomes the prevailing color. Where decomposition, leaching, and trituration have gone on to such an extent that the soils are composed almost entirely of silica, they may become very light gray or almost white, especially in the surface soils, where organic matter helps to reduce the iron compounds.

The above changes have taken place largely during the transition from rock to soil, but there are others, either resulting from these or going on in the soil itself, that are probably of equal importance, although most often overlooked. Among these may be mentioned differences (1) in structure and erosion as a result of freezing and thawing and (2) in the amount and character of the organic matter. The latter is in part dependent upon the former.

Freezing and thawing loosens up the soil and gives it a more open, porous structure and better tilth. In northern latitudes the soil is frozen to a depth of several feet, but the depth decreases southward until in the latitude of North Carolina it amounts to only a few inches, while as far south as Florida even the surface is practically never frozen. The effect is more pronounced in the subsoils than in the surface soils, because the latter are loosened up by cultivation, while the former are seldom disturbed by other than natural forces.

It is a well-known fact that erosion is much more pronounced in the South than in the North. This is due in a large measure to climatic influences, of which freezing is one of the most important. In the North erosion is almost entirely prevented by freezing during the winter, while in the South it is very active because of the general absence of vegetative covering at this season of the year. In the latter section freezing and thawing, together with cultivation, loosen up the surface soil to a depth of a few inches, but the subsoil is left in such a compact condition that a rapid rainfall can not be absorbed and must run off, carrying the soil with it. The more open structure of the subsoil in the North, due in a large measure to the deep freezing, allows all or nearly all of the water to be absorbed, especially in cultivated fields, and less erosion takes place. The conditions in the North are favorable to the formation of a sod which protects the surface from washing.

SOIL-FORMING MATERIAL.

While the various processes of soil formation have a profound influence in determining the character of the soil, difference in the rocks or soil-forming material also produces important variations in its nature. When it is recognized that the rocks are not only the source of the inorganic portion of the soil, but also have an effect upon the amount and character of the organic portion, this fact becomes very evident. Because of this relation between the soil and the underlying rock it has often been asserted that a geological map would answer as a soil map. In some cases the resemblance between the two is very striking, while in others very little or no similarity is evident. A good example of the former may be seen by comparing the soil map of Grainger County, Tenn., with the geological folio covering the same area, while an equally good example of the latter may be seen by reference to the soil and geological maps covering some of the counties on the Eastern Shore of Maryland.

In Tennessee the same geological formation is fairly uniform in character over large areas, although the separate formations are very markedly dissimilar. In Maryland each formation shows considerable variations, though portions may be very similar in character to another formation. In addition, differences in the drainage conditions, with the consequent variations in the soil-forming processes, have resulted in very pronounced modifications in the resultant soils.

Then, again, different geological formations may be identical in mineralogical composition, and, under the action of similar processes, will therefore give rise to similar soils, while the same formation may vary sufficiently in its physical and chemical nature to cause most important changes in the soils. The Tertiary and Quaternary deposits in the Panhandle of Texas, for example, are so similar that they can not be separated, except by the fossils. A lithological map would undoubtedly show closer resemblance to a soil map than a geological, but differences in the processes by means of which underlying rocks are converted into actual soils, as has been already emphasized in this paper, would often produce marked dissimilarities in the maps, even in this case.

Another factor which needs to be emphasized also is that a soil map is based almost entirely upon the character of the surface 3 or 4 feet of material, while a geologist would hardly consider such a layer of sufficient depth to indicate on a geological map. In Tama County, Iowa, the loess mantles the northern portion of the county to a depth of 3 to 6 feet, but is not indicated on the geological map, although shown in the southern portion, where it is deeper and overlies an older glaciation.

In geological classification the fundamental idea is age, in soil classification the character of the material. It may be stated, therefore, that in areas where the processes of soil formation are practically uniform, and the differences in geological formations represent differences in the character, rather than the age of the material, there will be a very close resemblance between a geological and a soil map. Where these conditions do not exist, then no definite relation between the two need be expected and usually does not exist.

It is not intended in this connection to go into a detailed discussion of the numerous kinds of rocks as soil formers, as this more properly belongs to the detailed description of the various soils, but there are some things which can be discussed to better advantage now than later.

Emphasis needs to be laid upon the point that in soil studies rocks are to be viewed simply as the source of the inorganic portion of the soil and that those differences which are most influential in determining the content of the relatively most important soil constituents, such as lime, sand, and clay, must be given most consideration. Actual differences in character rather than the age or the method of formation of the material should be stressed most. These differences usually represent, and in fact are often the direct result of, variations in the rocks, and for this reason the latter should be carefully studied; but when they do not influence the character of the soil they should be subordinated or entirely eliminated from the equation.

In considering differences in rocks it is well to keep in mind that they are due, as in the case of soils, to two sets of factors: First, the composition of the material out of which the rocks were formed, and, second, the processes of their formation. Both of these sets of factors have had their effect, sometimes one, sometimes the other predominating. Because certain deposits have been formed by the same agency does not necessarily mean that they are similar. Very different rocks may have been formed by the same agency and very similar rocks by a different agency.

Take, for example, the unconsolidated deposits formed by glacial action. These deposits have certain characteristics which distinguish them from those laid down by water, but differences in the rocks which have been ground up by the ice may cause wide variations in the nature of the glacial material. Where the mantle of drift is thin the influence of the underlying rock is predominant. In parts of New England, for example, thin glacial drift on granite gives the Gloucester soils; in the Hudson River Valley thin drift on limestone gives the Dover soils and on slates the Dutchess; in southern and western New York thin drift on shales and sandstones gives the Volusia. Practically all the glaciated section of the United States east of Ohio, and to a less extent west of this State, has only a thin covering of drift.

Likewise alluvial deposits vary with the character of the rocks from which the material composing them has been eroded. A very striking example is found in Texas. The large streams, like the Red, Brazos, and Colorado, which issue from the Permian Red Beds, have red soils along them, while the Trinity and Navasota, which rise in the black waxy lands, are bordered by very black soils. Farther west the Rio Grande and some other streams coming from the arid regions have light-colored, very calcareous deposits within the zone of their influence.

As the alluvial material varies according to the character of the rocks in the country through which the streams flow, or have flowed, the character of all sedimentary rocks will depend more or less upon the nature of the material brought down by the streams at the time of their formation. Of course, the material may have been further modified by wave action, as was undoubtedly the case in most of the deposits of the Atlantic Coastal Plains.

Emphasis has already been laid upon the important part which climatic factors play in soil formation. Their influence is no less evident in determining the composition of many of the rocks, especially those of sedimentary origin. Deposits composed of material brought down from the arid regions contain, as a rule, a much larger percentage of soluble matter than those from humid regions. This is well illustrated in the Tertiary formations of the Coastal Plains. As one passes from Louisiana southwestward through Texas toward the Rio Grande a gradual change in the material is very noticeable. The percentage of other minerals than quartz, as well as the amount of lime and other soluble matter, increases until near the Mexican border conditions very different from those in Louisiana are found. This change is due largely to the fact that the material has been brought from more and more arid regions as one passes toward the Southwest.

Many of the sandstones and shales of the Great Plains region are composed of rock material which, under the arid conditions, was broken up very largely by mechanical agencies, and their mineralogical composition is therefore not very unlike that of the glacial drift which was ground up by the action of ice. For this reason the two formations give rise to almost similar soils, although the rocks are of different origin.

Some of the factors which are considered of much importance from the standpoint of rock classification may be of little or no consequence when viewed from that of the soil. Rocks belonging to widely separated groups and having different names may give rise to very similar or even identical soils. The composition of granite and gneiss, for example, is essentially the same, the distinction between the two being made upon structure and origin. When these are broken down and converted into soil it is usually impossible to distinguish between the resultant products. Fragments of granite or gneiss may be transported and deposited so as to form an arkose sandstone, which upon weathering will give a soil very similar to that derived from the original rock. An example may be seen in the Triassic basin west of Richmond, Va., and also in North Carolina. Better illustrations, however, can be found in the more arid sections, where the breaking down of the rocks is accomplished almost entirely by mechanical agencies with little change in the chemical composition. Secondary rocks may be formed of this material which will give soils indistinguishable from those derived directly from the original rocks. In this way practically the same type may be of residual, colluvial, sedimentary, or even alluvial origin.

On the other hand, rocks having the same name do not necessarily give rise to the same type of soil, even when the processes of weathering are identical. In the Piedmont Plateau granite sometimes yields a red clay, sometimes a sandy loam with a red clay subsoil, and again a sandy loam with a yellow clay subsoil. The presence or absence of certain secondary minerals or even a change in the proportion of the essential constituents, is largely responsible for these variations, although erosion, by removing the rock material almost as rapidly as broken down, thus lessening the relative effect of decomposition, has often had a decided effect. A small percentage of quartz with a large amount of feldspar and hornblende, or some other iron-bearing mineral, tends to give the red clay, while a binary granite composed of quartz and feldspar weathers into a very siliceous, sandy soil with a yellow clay subsoil. In the case of limestone the impurities largely determine the nature of the residual product, although they may constitute only a very small percentage of the original rock.

Considerable space has been given to this discussion because of a more or less general failure to recognize the importance of many of these factors in arriving at a true conception of the nature, properties, and relation of soils.

CLASSIFICATION OF SOILS.

NEED OF CLASSIFICATION.

From the foregoing discussion it is evident that many influences and factors have been instrumental in giving to the soil its present properties and characteristics. Numerous kinds of rocks or soil material, subjected to the action of so many agencies and processes, with an ever-changing degree of intensity, have resulted in the formation of many varieties or types of soil, related to each other in various ways.

In the study of soils, as well as any other subject which has to do with a large number of individuals, classification is of the utmost importance in order that the various and complex relations may be shown as far as practicable. A complete and perfect classification will give an epitome of our knowledge in regard to any subject. Such, however, can not be made until a thorough understanding of the properties and characteristics of the objects to be classified is had—a condition far from being attained in our present imperfect knowledge of soils. Much valuable work, however, has been done and the knowledge thus obtained is being used as an aid to further studies. No more fundamental work than the proper classification and correlation of the soils of the country confronts soil investigators to-day, for this information is essential to the final solution of some of the most important questions with which they have to deal. Natural phenomena are always difficult to classify, because the various individuals merge into others by almost or entirely imperceptible gradations. No sharp lines of division exist, and such as are drawn must be more or less arbitrary. This fact is as truly applicable to soils as to any other great group of natural objects.

The need of arranging soils so as to show their relation to one another has long been recognized and some system of classification has been employed whenever the study of the soils of any extensive area has been undertaken. Different investigators, looking at the problem from different viewpoints, have used different bases of classification, each of which presents some important relation. One of the principal difficulties with most systems has been that they are founded upon one group of factors alone, while others of equal or even greater magnitude have been entirely neglected. A satisfactory system must be such that all of the important relations will be indicated, else it will not answer the needs of an enlightened agriculture.

PRINCIPAL BASES OF CLASSIFICATION.

In order to secure as full and clear an understanding of this subject as possible it is well to consider the principal bases, or systems, which have been used in classifying soils. These may be grouped under the following heads: (1) Geological, including (*a*) the age, (*b*) the kind of rock, or lithological, and (*c*) the agency of rock formation, or dynamic; (2) physical, including (*a*) texture, (*b*) structure, and (*c*) color; (3) chemical; (4) vegetation, especially native, or ecological; (5) processes of soil formation, or climatic; and (6) a combination of all these.

GEOLOGICAL.

The geological basis of classification has been used very extensively in many countries and by many investigators. Most of the earlier soil work in this country consisted largely in descriptions of soils of the different geological formations. In France[1] and Japan,[2] especially at the present time, the main soil divisions are based upon the geological formations which are then divided according to physical characteristics. The geological basis of soil classification has usually been approached from the viewpoint of the age of the material, its mineralogical character or the agency of its formation.

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[1] See Rapport sur les Cartes Agronomiques par M. Adolphe Carnot, Ministère de l'Agriculture, Bulletin, 1893.

[2] See various maps published by the agronomic section of the Imperial Geological Office of Japan.

Age of rock.—As most of the earlier work upon soils was done by geologists, and as age is the principal factor upon which geological divisions are based, the classifying of soils according to the geological formation from which they have been derived naturally resulted. Peters,[1] for example, in his work upon the soils of Kentucky, divided them into Silurian soils, Subcarboniferous soils, Carboniferous soils, Quaternary soils, Recent Soils, etc.

The same idea of age is involved in the separation of glacial soils according to the different advances of the ice, as has been done by Hopkins[2] in Illinois and Stevenson[3] in Iowa. The principal reason for this separation is the greater amount of leaching to which the earlier glaciations have been subjected. This does not depend, however, entirely upon the length of time that the material has been exposed. The topography of the country, the permeability of the material, as well as the climatic conditions, have much to do with this also. The geologists themselves are often uncertain as to the time and number of advances of the ice, so that it is not wise to follow these separations very far; too many other factors have relatively so much greater influence upon the nature of the soil.

In general, it might be said that, so far as age has actually produced differences in the soil, it should be given due weight in classification, but when such is not the case it should be entirely ignored.

Kind of rock, or lithological.—As the soil consists very largely of mineral matter formed from the breaking down of the rocks, its nature must necessarily depend to a large extent upon the kind of rock from which this material has come. This has led to the classification of soils according to the kind of rock from which they have been derived. Thus we have granite soils, shale soils, limestone soils, etc., expressive of the relation existing between the rock and the derivative soil.

If the same kind of rock always gave the same kind of soil, and the same kind of soil was always derived from the same kind of rock, this classification might answer all practical requirements. Such, however, is not the case, as was shown in the discussion of the relation of soils to the underlying formation, and while this classification embodies essential features, it is incomplete and therefore in itself unsatisfactory.

Agency of deposition.—Probably the most frequent basis of classification is what is commonly termed "origin," although in this connection the term is used with a somewhat restricted meaning. In this system the soils are usually divided into residual or sedentary and transported, according to whether they are derived from the breaking down of the underlying rock or from material which has been transported since it was broken down. The latter are further divided into (1) colluvial, (2) alluvial, (3) æolian, and (4) glacial, according to the agency of transportation.

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[1] Geological Survey of Kentucky, 1885, vol. 2, p. 160.

[2] The Fertility in Illinois Soils, by Cyril G. Hopkins and James H. Pettitt, Bul. 123, Illinois Experiment Station. See especially soil map and pp. 193–194 and 257.

[3] The Principal Soil Areas of Iowa, by W. H. Stevenson, Bul. 82, Iowa Experiment Station.

While the above division has been used by many investigators, scarcely any two agree as to the exact line of separation. Merrill,[1] for example, uses colluvial deposits to "include those heterogeneous aggregates of rock detritus commonly designated as talus and cliff débris," and states that they are "comparatively limited in their extent." He practically confines them to gravitational deposits. Hilgard,[2] on the other hand, says that "when the soil mass formed by weathering has been removed from the original site to such a degree as to cause it to intermingle with the materials of other rocks or layers, as is usually the case on hillsides and in undulating uplands generally, as a result of rolling or sliding down, washing of rains, sweeping of wind, etc., the mixed soil, which will usually be found to contain angular fragments of various rocks and is destitute of any definite structure is designated as a colluvial one." The latter definition is thus seen to be much more inclusive than the former.

Most investigators are agreed that sedentary or residual soils consist of those which are formed in place, but there is a difference of opinion as to what constitutes formed in place. The more common usage is to confine residual soils to those derived from hardened rocks, while those formed from unconsolidated deposits are called transported, and these terms are used in this sense in this report. However, the soils derived from the unconsolidated sandy clays and clays of the Atlantic Coastal Plains are as truly formed in place as those from older consolidated rocks. In a strict sense, only the most recent alluvial soils are transported soils; practically all others are derived from the underlying material, although this may have been previously transported by water, wind, or ice.

Differences in the agencies of transportation of soil material necessarily determine to a certain extent its character and, consequently, the nature of the resultant soil, but differences in the physical, mineralogical, and chemical composition of the material transported, together with changes produced by variations in the soil-forming processes, may so overshadow these, in some cases at least, as to render them almost if not entirely negligible.

This classification takes into consideration only one phase of the origin of soils, the geological, while the biological and climatological are omitted. In short, it fails to show some of the most important physical, chemical, and biological relations between soils, relations of the utmost significance to the agriculturist, in whose interest any system of soil classification is primarily made.

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[1] Rocks, Rock-weathering, and Soils, by Geo. P. Merrill, p. 319.

[2] Soils, by E. W. Hilgard, p. 12.

PHYSICAL PROPERTIES.

That soils differ in physical properties and that these differences have an influence upon the growth of plants has long been recognized by practical agriculturists as well as scientific soil investigators, but it is only within comparatively recent years that the importance of these properties has been appreciated. The work of Whitney, King, and Hilgard has done much to bring about this result. The three most important physical properties to be considered in soil classification are texture, structure, and color.

Texture.—The term "texture" is employed somewhat loosely in soil literature. As used in this paper it has reference to the relative proportion of the different grades or sizes of particles, while structure refers to the arrangement of these particles. The necessity of distinguishing between the two is at once evident. The former remains practically constant, while the latter is continually changing. Every time a field is plowed the structure is changed, and every rain that falls afterwards makes additional changes in the arrangement of the particles. As texture is a property that remains practically constant, it can be used as a basis of classification, but only those differences in structure which are due to the inherent character of the material can be considered.

According to texture, soils are divided into a number of classes, as sand, sandy loam, loam, clay loam, and clay. The number of classes will depend upon conditions. Whenever the difference in texture is sufficient materially to influence plant growth, a separation, if practicable, should be made, although the fineness to which these divisions shall be carried depends upon the amount of detail desired. The five classes just given are the ones most commonly recognized, but in detailed work three or four times this number have to be made. In addition, the presence of stones or gravel necessitates the introduction of stony and gravelly members of the different classes also. There is need of large textural groupings, with subdivision of each group, in order that this classification may be adapted to any amount of detail to which one may wish to go.

The diagram given below shows the distribution of the material as obtained by averaging the mechanical analyses of a large number of soils in the 12 most important soil classes. It does not necessarily represent the most typical distribution.[1]

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[1] See Physical Principles of Soil Classification, by George N. Coffey, Proceedings of the American Society of Agronomy, vol. 1, p. 181.

This textural classification is undoubtedly of the very greatest importance, and any system of which it does not form a part can not be satisfactory. On the other hand, the fact that in this system texture is the only factor considered and the further fact that it has been found necessary to recognize as many as 50 to 75 types having the same texture, shows that it can not in itself answer all the requirements. The importance of considering other differences besides texture can not be too strongly emphasized.

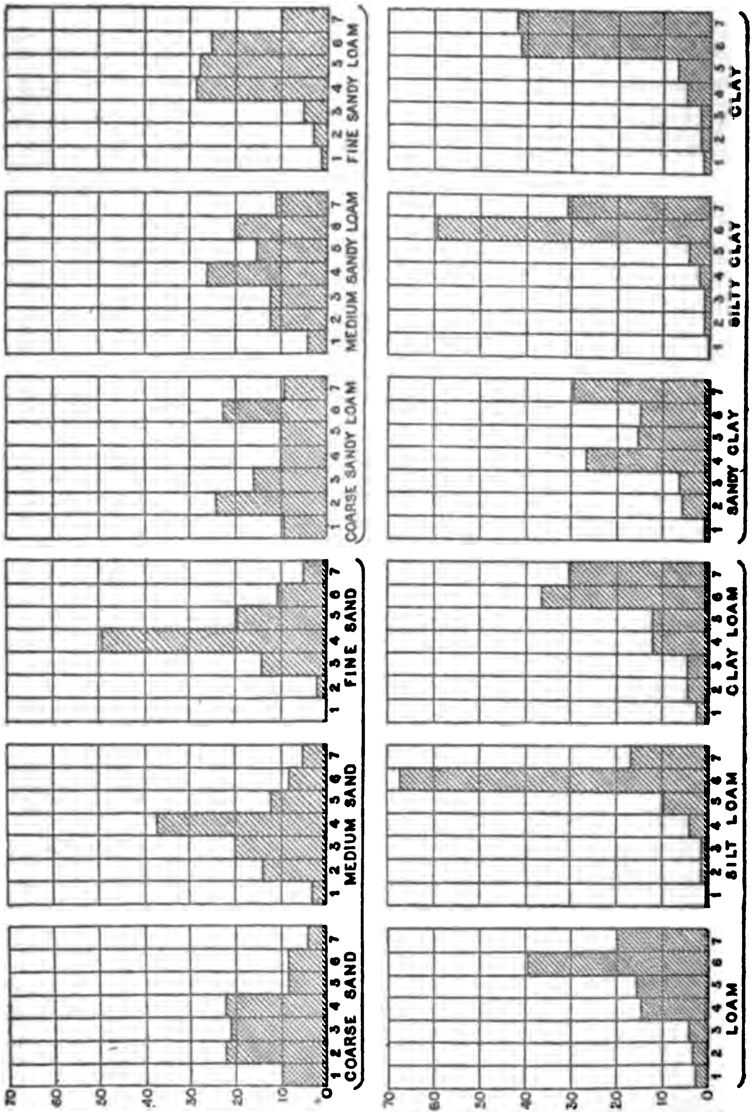

FIG. 1.—Mechanical composition of principal soil classes. The figures at the foot of the columns represent the following grades of material: (1) Fine gravel, 2 to 1 mm.; (2) coarse sand, 1 to 0.5 mm.; (3) medium sand, 0.5 to 0.25 mm.; (4) fine sand, 0.25 to 0.1 mm.; (5) very fine sand, 0.1 to 0.05 mm.; (6) silt, 0.05 to 0.005 mm.; (7) clay, 0.005 to 0 mm.

Structure.—Structure, or the arrangement of the particles, is another very important property of the soil, although one which is really very little understood. Porous or impervious, loose or compact are terms used to express differences in structure. While some of the differences in structure may be so artificial and transitory, like those induced by plowing, that they can not enter into the question of classification, still there are others which seem to be inherent in the nature of the mineral matter and no amount of manipulation can entirely eliminate them. The particles in some soils fit very closely together and good tilth is maintained with difficulty, while in others the arrangement is loose and cultivation easy. Numerous observations prove that subsoils, which shrink and swell a great deal as the result of a change in moisture conditions, are nearly always impervious. The cause of this is probably the presence of a large amount of "colloidal clay." Such differences in structure are easily discernable in the field, and while further study is needed to explain the cause, or causes, they should certainly be recognized in detailed soil mapping.

Color.—Color is one of the most obvious physical properties of the soil, one used by practical farmers as an index to its character from time immemorial. A black color has come to be almost synonymous with productiveness. "Red soils," "gray soils," "brown soils," "white soils," etc., are terms in very common use. In itself color may be of very little importance, but as an indicator of physical and chemical conditions it is of the greatest moment. The practical agriculturist will no more class together soils markedly dissimilar in color than the ethnologist would consider a white and a black man as belonging to the same race.

In judging soils by their color one must always consider to what this color is due, else entirely erroneous conclusions may be reached. In a humid region, for example, a white color is indicative of a soil poor in lime and "available" phosphoric acid as well as of low agricultural value. In an arid region this appearance is often due to the presence of large amounts of lime, and such soils are usually very productive when supplied with moisture.

While color is properly classed as a physical characteristic of the soil, probably its greatest significance is as an indicator of chemical differences. By its use it is often possible to detect differences which the present methods of chemical analysis are unable to explain. When its importance in chemical analysis is considered one can readily understand how valuable a factor it may be in judging of differences in the chemical condition of the soil constituents. In analytical chemistry certain colors are indicative of certain elements or compounds. The same is doubtless true of soils, although the conditions here are so complicated that the assumption may often be impossible of proof.

CHEMICAL PROPERTIES.

A great many chemical analyses of soils have been made and classifications according to the percentage of the different elements of plant food found in them have been undertaken. The mineral theory of plant nutrition advanced by Liebig gave the greatest stimulus to this line of soil investigation.

That differences in chemical composition have a marked influence upon soil fertility is not to be questioned, but no method of soil analysis has ever been devised by means of which the fertility of the soil can be determined with certainty a priori. There are so many factors which have an influence upon the growth of plants besides the mere amount of plant food present that the determination of this alone can never be used as a safe and sure guide to its agricultural possibilities. Even if a method could be devised, only a very small part of the soil in a field can be analyzed, and it is therefore necessary to use other means of distinguishing differences, else there is no way of knowing whether the surrounding soils are similar in character, and unless this is true the chemical analysis would be of practically no value. Chemical analyses may be used in the laboratory as a means of studying the causes of differences in soils, but a practical classification must be based upon those obvious differences which can be determined in the field. For example, one of the most important chemical differences in soils relates to their calcareous or noncalcareous nature. Several laboratory methods have been devised for determining this question, none of which are entirely satisfactory, and Hilgard[1] states that "the decisive feature in this matter must evidently be the native vegetation, which expresses the nature of the land much more clearly and authoritatively than any arbitrary definition or nomenclature can possibly claim to do. A soil must be considered as being calcareous whenever it naturally supports the vegetation (calciphile) characteristic of calcareous soils." It is possible, however, for a soil to be calcareous in the deeper subsoil and noncalcareous near the surface, so that it would support a deep-rooted calciphile and a shallow-rooted calcifuge vegetation. The writer doubts whether a soil should be considered as truly calcareous unless it has a sufficient amount of lime carbonate to give the dark tint to the humus, provided moisture conditions are favorable.

It is nearly always possible for a soil expert to detect, by means of color, origin, native vegetation, or crop growth, the existence of important chemical differences in soils, although he may not be able with our present methods to explain the exact cause or nature of the differences. If they can not be detected by these means they are not usually of sufficient importance to justify giving them consideration in soil classification.

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[1] Soils, by E. W. Hilgard, p. 496.

NATIVE VEGETATION.

The most important function of the soil is the support of plant life. The kind of plant life which is found is dependent more or less upon the character of the soil, and this fact has been made use of by some investigators as a basis of classification. One of the most ardent advocates of this basis is Hilgard, who used it in the Tenth Census as the principal foundation for dividing the soils of the Cotton States into broad groups and regions. In his recent book on "Soils" the same author has devoted the entire fourth part to a discussion of "Soils and Native Vegetation." Peters used it to some extent in his work upon the soils of Arkansas and Kentucky, and other investigators have given it more or less attention. Hilgard laid especial emphasis upon the native vegetation. The same principle, however, has been applied in classifying soils according to the crops grown upon them. Thus we have corn soils, cotton soils, wheat soils, pineapple soils, etc. The character of the crop grown, however, depends too much upon economic conditions to use this as a basis of soil classification. A study of the adaptation of soils to different crops is very profitable, and the Germans especially have done much work along this line, but it is more a classification of land than of soil.

There is no doubt that a change in native vegetation is usually indicative of a change in soils, but there are striking exceptions. In many instances where there is a marked difference in the natural timber growth it is possible to find differences in the soils to explain it, but in other instances markedly different soils will show the same character of timber growth. The post and black-jack oaks seem to thrive best upon soils subject to drought. This condition may be found in both deep sands and impervious clays and these trees are found upon both kinds of soil.

It is also a well-known fact that where one kind of timber growth is removed trees of a different genus often take possession of the land. It is a matter of common observation that when fields originally covered with deciduous trees, like the oak, are abandoned, there almost invariably springs up a growth of pine, and this is so common that the tree has received the name of "old-field pine."

A fundamental essential of scientific classification is that it must be based upon inherent and invariable properties of the materials classified. Classifying soils according to native vegetation is therefore going at the matter backwards; it is putting the effect before the cause. It is better to determine the cause of the change in the vegetative covering, and, if found to be due to a variation in the soil, base the classification upon this; otherwise the destruction of the vegetation will destroy the foundation of the system. Vegetation should, therefore, be used as an indicator of agricultural value and an aid in rather than a basis of classification.

CLIMATIC.

That soils formed under arid and humid conditions are essentially and strikingly different in character is clearly recognized by all investigators who have made any study of the subject. As has already been pointed out, this is primarily due to differences in the processes of weathering resulting from the markedly dissimilar climatic conditions, especially moisture, although temperature also has an influence. This contrast in the soils of different climates has led to their classification upon this basis, or, more strictly speaking, upon the differences which have resulted from a dissimilarity in climatic conditions.

While American and other investigators have generally recognized the influence of climatic factors in soil formation, Russian workers, especially Dokouchayev, who is credited with founding a new school of soil investigation, have laid greatest emphasis upon the importance of climate in soil classification. With them it is given first place, because all processes of soil formation or weathering vary more or less with the climate, and therefore soils formed under markedly dissimilar climatic conditions will be very unlike in character. The climatic classification coincides to a certain extent with the chemical and geological classification. According to this classification, the world has been divided into the following "soil zones:"[1]

(1) Laterite soils, or soils of the warm, humid Tropics and Subtropics.

(2) Eolian dust soils, formed in continental regions of dry climate.

(3) Soils of the dry or desert steppes.

(4) Chernozems, formed in connection with herbaceous steppes and prairies of the temperate or cold temperate zones.

(5) Soils of the wooded steppes and of the deciduous forests, resembling the chernozems, but distinguished by conditions of origin.

(6) Peat soils and Podzols, properly soils of a cold temperature. They are typically developed under the mixed forests and are ordinarily accompanied by "ortsteins."

(7) Soils of the tundras, formed upon the clay and sandy tundras.

COMBINATION.

Since all of these viewpoints represent more or less important relations between soils, it is evident that any system based upon one set of factors alone is not entirely satisfactory, and attempts have therefore been made to construct a system by combining one or more of these.

In France, for example, a commission was appointed in 1893 to report upon all matters connected with the making of agricultural maps. This commission[2] recommended that geological maps be used as the basis, and that the variation in sand, clay, lime, and humus of the geological formation be shown by the initial letter of the proper ingredient.

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[1] See Etude des sols de la Russie, by N. Sibirtzev, Seventh International Geological Congress, St. Petersburg, 1897. Also Russian Soil Investigations, Expt. Sta., Record, Vol. XII, pp. 704–712 and 807–888.

[2] Rapport sur les Cartes Agronomiques, par M. Adolphe Carnot, Ministère de l'Agriculture, Bulletin, 1893.

Pagnoul[1] classified soils according to the amount of humus, lime, sand, and clay. They are divided (1) into ordinary soils, having less than 50 per cent of humus, and (2) humus soils, having more than 50 per cent of humus. Ordinary soils are subdivided into calcareous, clayey, and sandy, and a combination of these gives further subdivisions.

In Germany the Prussian Geological Survey has constructed many "Geologisch-agronomischen" maps. In the general description of these it is stated that "the explanation accompanying each colored map contains a geological and an agricultural part. In the latter the weathering processes and the nature of the several soils are described. These are divided into groups according to the chief soil components, and are loamy, sandy, clayey, humaceous, calcareous, etc.

The classification used upon the Japanese maps is based upon geology, which is shown in colors, while the physical characteristics—sand, loam, clay, etc.—are indicated by hatching over the colors. By means of symbols the soils are divided into those "rich in humus" and those "moderately rich in humus." The Japanese classification is therefore much like that of the French and Germans.

As already pointed out, the Russians make their primary classification upon the origin of the soil—not so much the geological as the climatic and organic origin. Taking the origin as the starting point, the classification is elaborated and further subdivisions made according to differences in texture or other physical and chemical properties.

The system of classification used by the Bureau of Soils of the United States Department of Agriculture is founded upon those differences which are obvious in a field examination. In one sense it is therefore largely physical, but many of these differences are due to geological, chemical, or biological causes, and it is therefore proper to say that these factors are also given a place. In fact, all features which have any obvious influence upon plant growth are taken into consideration.

From a study of the soils in various parts of the United States, it has been found possible to divide the country into a number of provinces, each of which contains soils peculiar to itself. This is due to a similarity in the geological processes by which the soil material in these provinces has been formed. Thirteen such provinces have thus far been recognized.[2]

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[1] Les Terres Arables du Pas-de-Calais, par A. Pagnoul.

[2] See "Soils of the United States,' by Milton Whitney, Bul. 55, Bureau of Soils, U. S. Dept. Agr., p. 27.

Owing to variation in the source of the material or in the processes of weathering, soils may differ in character and appearance, although formed by similar processes. The soils of a given province are therefore further divided into series, which consist of soils very similar in all characteristics except texture. Soils are made up of particles of various sizes or grades, and the relative proportions of the different grades determine the texture. Different divisions of soils based upon texture have thus been established, and the soil series is subdivided into different classes. A combination of the series and class characteristics constitutes a type. which is the unit of soil classification. An example will suffice to illustrate the system:

Province	Piedmont Plateau.
Series	Cecil.
Class	Clay.
Type	Cecil clay.

IDEAL.

The ideal classification would be one in which the individual types are grouped in a number of divisions, each larger grouping representing more and more distant relationships in the soils. Thus in one of the major divisions there would occur no type which closely resembles any soil in any of the other divisions. The working out of such a system in detail would require a complete knowledge of the soil and of the relative influence upon plant growth of the numerous factors which constitute soil differences. Such knowledge is far from realization, if not indeed absolutely unattainable.

In making such a classification it would be necessary to recognize inherent differences in the soil itself as the fundamental idea; to consider it as a natural body having a definite genesis and distinct nature of its own and occupying an independent position in the formations constituting the surface of the earth. The various constituents which make up this bio-geological formation would have to be studied and their relative influence upon ecological relations determined. The major divisions should then represent differences in the most influential of these constituents and further subdivisions made upon those of less consequence.

The task is made more difficult by the fact that the relative importance of the various differences may change with a change in any of the other interdependable factors or conditions. In regions of dry farming, for example, texture is of very great importance because of its pronounced influence upon soil moisture, which is the determining factor in successful agriculture in the semiarid regions. In an irrigated district, on the other hand, the moisture supply is under human control, and texture, therefore, loses its prominent position.

Likewise differences which have a decided effect upon the growth of one plant may have little significance if some other crop be grown. Alfalfa will not do well upon any soil that does not contain a considerable amount of lime, but wheat or corn will grow upon both calcareous and noncalcareous soils, although there is strong evidence to show that the same variety will not produce equally well on both. On account of these and other difficulties, it seems that it will never be possible to construct an ideal system of classification, although it is well to have it in mind and to make our classification correspond as nearly as possible to the ideal one.

GENETIC.

In the first part of this paper it was shown that all differences in soils are due to variations either in the processes of derivation or in the character of the material from which they have been formed through weathering; in other words, to origin in the broad sense of that term. A classification based upon differences due to these two sets of factors may, therefore, be termed genetic. The question naturally arises as to which of these shall constitute the basis for the larger groupings.

In considering the constituents of the soils the great importance of humus, lime, and clay was pointed out, and in view of their preeminent influence in determining the relation of the soil to crops, it is evident that the larger division should represent, as far as possible, differences in the proportion of these constituents. The study of the soils of a large area like that of the United States shows that the percentage of humus and lime, and to a less extent of clay, depends very largely upon the amount of leaching which has taken place, and, therefore, the processes of derivation rather than the character of the material should be used as the basis for the larger divisions. As these constituents vary with the climate, especially the amount of precipitation, the major divisions, while representing variations in the most important constituents, will correspond rather closely to climatic regions. For convenience, therefore, we might say that the primary divisions are based upon climate, although strictly speaking they are based upon differences in the soil which are due to variations in the processes of formation resulting from dissimilar climatic conditions.

Emphasis, however, should be laid upon the fact that differences in climate are of importance in soil classification only in so far as they have produced variations in the nature of the soil. Other factors may come in and intensify or diminish the action of the processes sufficiently to make it impossible to draw the line of division strictly upon the amount of precipitation. In Alabama and Mississippi, for example, the very calcareous and only slightly consolidated nature of the Selma chalk (Cretaceous) has caused the formation of Dark-colored Prairie soils in a region where the rainfall is approximately twice the average of that in the great prairie belt. In the limestone valleys of the Appalachian region the rainfall is no greater than in Alabama, but the hard nature of the rock makes necessary a long lapse of time for its degeneration, and the lime, which is essential in the formation of the dark prairie soils, is leached out. These Prairie soils in Alabama and Mississippi should be grouped with other Prairie soils, though they lie in a region of much greater rainfall.

Differences in topography and in the nature, especially the texture, of the material will also have an influence upon the amount of leaching that will result from a given rainfall. As these determine almost entirely the amount of moisture which remains in or upon the soil, they bring about marked variations in its character. Constant saturation, for example, will cause the accumulation of organic matter and result in the formation of Black Swamp soils or, in extreme cases, of muck and peat.

While these variations in the processes of soil formation thus give rise to differences in the percentage of lime and organic matter, they also affect other essential, although less important, soil constituents. The best illustration is the large amount of soluble salts found in connection with lime in the arid regions. A grouping of the soils upon differences due to the soil-forming processes, or climatic origin, will not only represent marked contrasts in the important soil constituents—lime and humus—but will also coincide with variations in many other ingredients. As the climatic conditions are generally fairly uniform over extensive areas the major divisions will usually embrace large stretches of country and represent such profound dissimilarities in both soil and climate, which constitute the two parts of a plant's environment, that the variety of crop suited to the soils of one division need not be expected to do well in another.

Upon the above factors or differences the soils of the United States can be divided into a number of divisions, each division being distinguished by soils having certain more or less well-defined characteristics. As the climatic conditions change gradually rather than abruptly from one section of the country to another, the soils of one region will likewise merge into those of an adjoining region, with usually no sharp line of division. In fact, near the boundaries, or where the differences are due to drainage, there may be small areas of one kind surrounded by another. The following divisions may be recognized in the United States: (1) Arid or unleached soils—low in humus, (2) Dark-colored Prairie or semileached soils rich in humus, (3) Light-colored Timbered or leached soils low in humus, although containing considerable organic matter, (4) Dark-colored Swamp or leached soils high in organic matter, and (5) Organic or muck and peat soils. Of these divisions the last two are of local development, and, therefore, of much less importance than the other three.[1]

While extremely important soil differences, as represented by these major divisions, have resulted from dissimilarity in the process of weathering or climatic origin, other differences due to variations in the character of the material or geological origin, occur within the above division (except peat and muck) so that further subdivisions of these can be made from this viewpoint.

In studying this phase of the subject it will be found that variations here are likewise due to differences in the agency of deposition and in the nature of the material deposited. The first is the basis of subdivision most commonly used in classifying soils, and while a difference in the agency of deposition does not necessarily imply an unlikeness of the material, or vice versa, such is usually the case. A knowledge, therefore, of the agency concerned in the formation of the soil material will aid in reaching a proper understanding of the true nature and properties of the soil. Where these agencies have had little appreciable effect upon the soil-forming material too much stress should not be laid upon them.

According to differences in the agencies or method of formation of the rocks, subdivisions of the major soil groups can be made. The following are suggested: (1) Soils from crystalline rocks formed through the agency of heat and metamorphism; (2) soils from sandstones and shales or consolidated material deposited by physical agencies; (3) soils from limestones formed by organic agencies or as chemical precipitates; (4) soils from ice-laid material (glacial); (5) soils from unconsolidated water-laid material (sedimentary); (6) soils from wind-laid material (æolian); (7) soils from gravity-laid material (colluvial); and (8) alluvial soils representing recent stream material deposited as actual soil.

Not all of the rocks formed by the same agencies or processes consist of identical material, and therefore variation in the soil derived from them is the result. In some cases the difference may be physical, in others mineralogical, and in still others chemical. We may thus have the same material overlying gravel or clay; may have alluvial soils washed from limestones or granite; may have glacial material composed of ground-up shale or limestone; or there may be sedimentary deposits rich in iron, or some other elements, while other deposits will contain these elements in only small amounts. For this reason further subdivision of the soils, even though derived from rock formed by the same agencies, becomes necessary. These differences are usually more easily detected by color than otherwise, and the division into series might be considered as based more upon this property than any other, although other factors are, in some cases, used also. The soils of a series are similar in all other characteristics except texture. Owing to the fact that very nearly similar soil material may be deposited by different agencies there may be a closer resemblance in two series formed from rocks of different origin than between two derived from rock of similar origin. For this and other reasons a classification based upon difference in the soil itself would be more desirable and some time will doubtless be made.

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[1] Two other divisions might possibly have been added, "alkali" soils, representing an excessive accumulation of soluble salts and semiarid soils or slightly leached surface soils containing considerable humus but having unleached subsoils. As the former can be so readily changed by leaching out the injurious salts it seems best to consider the "alkali" soils as a variation of the arid, while the semiarid constitute a transition from the Arid to the Dark-colored Prairie soils.

It has already been pointed out that texture is the most important physical property of the soil. According to differences in this property the series are divided into classes, or into sand, loam, clay, or some intermediate class. In order to bring out the importance of this property of the soil, the texture is made a part of the type name.

There are undoubtedly a large number of soil series, and it is possible in this paper to describe only some of the more representative. In some cases no division of the larger groups into series was attempted.

ARID SOILS.

The distinguishing characteristics of the Arid soils are (1) a large quantity of soluble mineral matter, (2) low content of organic matter, (3) generally gray or light color, (4) deep soils with little change in character with depth, (5) small quantity of clay, especially in the subsoil, unless formed from clay deposits, (6) less siliceous nature of the sand, and (7) marked productiveness when irrigated.

On page 15 is given a table showing that the average percentage of soluble salts in the soils of the arid regions, as determined by the electrolytic method and obtained by averaging the results secured in testing 155 samples, is one-third of 1 per cent (0.333 per cent), or slightly more than twenty-five times the average for the humid region. While the electrolytic method gives only approximate results, the above figures show conclusively and strikingly that the Arid soils have a much larger percentage of soluble salts than the humid. So large, indeed, is the quantity that a constant movement of water from below, and its evaporation at the surface, will result in the accumulation of these salts in sufficient quantity to injure or prevent plant growth, and the soil is then called "alkali."

A marked variation in the quantity of soluble material present is, however, shown by the determinations—five samples (sands) out of 155 falling as low as 0.01 per cent while nine samples were above 2 per cent, the highest containing 5.50 per cent. The lower percentages are probably due to the small amount contained in the original material or to leaching by river action, while the higher ones represent areas where the salts have been concentrated by the movement of water and evaporation.

The presence of this large amount of readily soluble mineral matter is the result of the processes of formation. As was pointed out in another part of this paper, in an arid region mechanical processes predominate over chemical. The low precipitation precludes much leaching, and the soluble material is left in the soil instead of being carried off by drainage waters. The greatest contrast is in those elements or compounds which go into solution most readily and are therefore leached out in a region of heavy precipitation.

Lime is one of the most soluble as well as important compounds found in the soil. It is abundant in the Arid soils, as may be easily seen by testing with acid, there being very few of these soils which do not have a sufficient amount to effervesce freely with acid. The proportion between the lime content of the soil of the arid and humid regions has been estimated[1] at about 11 to 1, the average for the Arid soils being 1.43 per cent. As this average does not include soils derived from calcareous formations, it is probably too low rather than too high. When we consider the many important effects of lime carbonate, the significance of this large amount can not be easily overrated.

While lime is the most important soluble compound, almost as striking differences exist as regards others. It is not possible, however, in this paper to go into a detailed discussion of this matter, but a very good idea can be obtained from the table from Hilgard given on page 14. It is well to call attention to the much smaller percentage of "insoluble residue" in the Arid soils.

An examination of the sand simply with the eye is sufficient to show the relatively larger percentage of other minerals than quartz present, and from the mineralogical analysis given on page 87 it would seem that these seldom fall below 25 per cent, while the average for the three series (30 samples) is about 38 per cent, which doubtless accounts for the greater productiveness and more lasting quality of the sandy soils of the arid regions as compared with those of the humid.

While the Arid soils are high in soluble mineral matter, they are low in humus; although the nitrogen content of this is about three and a half times that of the humid.[2] The absence of much humus is indicated by the light color of the soils, which would not exist if a large amount were present. The dry, desert condition that usually occurs in the arid regions not only prevents the production of much organic matter but also furnishes conditions favorable to the rapid disappearance of that which is formed.

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[1] Soils, E. W. Hilgard, pp. 377–381.

[2] Hilgard and Jaffa, on the nitrogen content of soil humus in the humid and arid regions. Rept. Cal. Expt. Sta., 1892–1894; Agr. Science, April, 1894; Wollny's Forsch. Geb. Agr. Phys., 1894.

The light color of the Arid soils has just been referred to and is quite general except in cases where the soils are derived from highly colored formations. The characteristic colors are difficult to describe, but are usually some shade of gray. One familiar with the gray soils of the arid and timbered humid regions can usually distinguish between them simply from the appearance. The former show a more even distribution of color, with few or no streaks and mottlings, which are usually due to imperfect aeration. The marked change which usually takes place at a few inches below the surface in the latter is also almost or entirely absent.

Not only is there practically no change in the color with depth but also very little change in texture and other properties. In fact the true soil here extends to a great depth, often several feet. If the surface soil be removed in the humid regions it will be several years before plants will thrive upon the exposed subsoil. In the arid, however, such results do not follow, good crops being secured upon freshly exposed material from several feet below the surface. Recent investigations are showing that bacteria are abundant at depths of several feet in the latter case, while in the former their number rapidly decreases after the subsoil is encountered. In fact, the Arid soils can hardly be said to have true subsoils.

The marked productiveness of the Arid soils when irrigated is too well known to need comment here. It was recognized centuries ago, and some of our earliest and most highly organized civilizations were developed in arid regions. While these soils are rich in plant food their great productiveness is not to be attributed to this alone. Some of the physical and biological factors doubtless play an important rôle also.

Since the distinctive characteristics of these soils are due to the dry conditions under which they have been formed, they will necessarily be confined to regions of low precipitation. The line of division can not be drawn at any particular amount of precipitation, for while this is the most important factor the character and distribution of the rainfall, the evaporation, the topography as affecting the run-off, and the nature of the soil formations have an appreciable influence and may cause considerable variation. In southern Texas,[1] for example, almost typical arid soils were encountered where the mean precipitation is as much as 20 inches or even more, while in North Dakota Dark-colored Prairie soils, producing good crops without irrigation, are found with even less rainfall.

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[1] Reconnoissance Soil Survey of South Texas, by George N. Coffey and party, Field Operations Bureau of Soils, 1909.

An examination of a precipitation map will show that the arid soils in the United States will nearly all be found west of the 103d meridian. Nearly all of New Mexico, Arizona, Utah, Nevada, southern Idaho, eastern Washington, and Oregon, eastern and southern California, and southwest Texas, as well as much of Colorado, Wyoming, and Montana have Arid soils.

SUBDIVISION OF THE ARID SOILS.

The soils of the arid region can be subdivided according to the agencies concerned in the origin of the soil material. It seems, however, that these factors do not necessarily produce as marked differences in the soils here as they do in the humid regions, and it is often difficult to see any very great difference between the soils of residual, colluvial, or even alluvial origin. As these soils are of little or no agricultural value until irrigated, and as most of the irrigation projects are situated in the valleys, most of the soils studied in this region are of sedimentary, colluvial, or alluvial origin. The area under irrigation is also comparatively small, so that no very definite knowledge of the soils of a large proportion of this part of the country has been secured. For this reason, and also because the writer has had little opportunity to make personal observations in this section, no further discussion of these soils will be attempted here, although many references to detailed studies are given in the bibliography.

DARK-COLORED PRAIRIE SOILS.

The most prominent characteristics of the Dark-colored Prairie soils are (1) a moderately high content of lime and other soluble mineral matter, (2) a high content of humus or organic matter in the condition which gives a dark color, (3) dark, or what is popularly called "black" color, except where this is masked by red iron oxide, (4) usually sharp and marked contrast, especially as regards color, between the soil and subsoil, and (5) generally high agricultural value.

As the rainfall in the prairie region may be two or three times as great as in the arid the amount of leaching that has taken place is correspondingly much greater and the soils therefore lower in soluble mineral matter. Very few samples were included in the determinations from which the table on page 15 was made up, but those given show an amount between that of the arid and humid. While the number of samples analyzed was insufficient to furnish more than an approximation, the true average undoubtedly lies between the other two. The amount is seldom sufficient to cause an accumulation of alkali. Naturally the percentage of soluble material increases as the border of the Arid soils is approached, while it decreases as the precipitation becomes greater. In the former section the depth to which leaching has taken place or organic matter accumulated gradually decreases until it coincides with the surface and the Prairie soils[1] change into the Arid. This gradation or transitional condition exists over a considerable belt and might possibly be considered as another soil division.

The Prairie soils are usually well supplied with lime and give an alkaline or neutral reaction. Often, especially in the subsoil, the percentage of lime is sufficient to produce a free effervescence with acid, and is always enough to give the dark tint to the organic matter.[2]

The large amount of humus and the consequent dark color is one of the most striking characteristics of the Prairie soils. Field observations have conclusively shown that a relation exists between this accumulation of black humus and the presence of a considerable amount of lime and moisture. For example, the Selma chalk in Alabama and Missisippi gives a dark-gray to black clay and typical prairie conditions. Whenever there is wash from this chalk into the bottoms the alluvial soils are black also, while elsewhere they are lighter shades of color. East of Madill, in Oklahoma, an outcrop of a thin layer of limestone[3] around a hill can be traced by the darker color of the soil.

If a soil is low in lime, intermittent wet and dry conditions will cause it to turn white and markedly decrease in productiveness, while if lime is present it will become very much darker and an increase in productiveness will take place. Whenever a truly alkaline or calcareous condition exists and a sufficient amount of moisture for vegetative growth is present the soil is certain to have a dark color. Numerous examples could be cited, but a sufficient number have been given to show that the origin of the Dark Prairie soils is due to a relation between the lime, and possibly other soluble material, and moisture. The location of these soils between the unleached Arid soils on the one side and the leached Timbered Humid soils on the other is the very strongest evidence of such relation.

Whether this accumulation of humus is due to lime alone or to the lack of leaching, of which its presence is an indication, has not been definitely determined. Neither do we know whether it is due to chemical or bacteriological action; most probably the latter, an alkaline medium being necessary for the growth of those bacteria or other microorganism which cause this form of decomposition.

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[1] For brevity and facility in expression, the Dark-colored Prairie soils will often be referred to simply as Prairie soils and the Light-colored Timbered soils as Timbered soils.

[2] According to Hilgard the necessary amount varies from about 0.2 per cent in sandy soils to 1 per cent in clay soils. Soils, by E. W. Hilgard, p. 369.

[3] This is mapped in the Tishomingo Folio, U. S. Geol. Surv., as the Bennington limestone.

In order to throw some light upon this question jars were filled with a light-colored loess soil from Illinois. To one jar green pea vines were added; to another the same, with the addition of a large amount of lime; to a third, in addition to the lime and pea vines, some black soil, for the purpose of supplying the proper bacteria. The soil in all the jars was kept moist, or as near in the natural prairie condition as possible. In all of these the organic matter disappeared without any apparent change in the color of the soil. It would seem, therefore, that something more than mere chemical action of the lime is involved. The presence of forms of life inimical to the bacteria which bring about the decomposition of the organic matter may be possible, and a further test with sterilized soil later suggested itself, but there has been no opportunity for trying this.

That the organic matter, or at least part of it, is, however, in a different form from that either in the Timbered or the Black Swamp soils is very evident from field observations, although the exact nature and cause of the difference has not been satisfactorily worked out in the laboratory. In the Prairie soils the processes of decomposition have apparently gone much further, and the dark color is due to a product of this decomposition, while the black color of Swamp soils is due to partially decomposed organic material. The Prairie soils can be cultivated for years without causing any great change in color, while the swamp soils become lighter in color very rapidly, showing that the organic matter is disappearing.

The amount of humus varies considerably, depending upon conditions, the most favorable for its accumulation being plenty of lime and sufficient moisture. The former is found where the underlying formations are very calcareous, and have not been subjected to much leaching, and the latter where the soils are retentive of moisture and have a level topography so as to prevent too rapid surface drainage. Porous soils are usually well drained and aerated, and are not most favorable for a large accumulation, therefore sandy soils usually have less humus than loams and clays. In the transition toward the arid region the lower precipitation causes a decrease in the vegetation and a consequent lighter color of the soils. Since a high temperature accelerates decomposition, other conditions being the same the soils of higher latitudes have more humus than those of lower latitudes. A combination of practically all these favoring conditions is found in the Red River Valley in eastern North Dakota and western Minnesota, and a very large amount of humus is here present.

A high percentage of humus and the resulting dark color causes a marked contrast between soil and subsoil. The zone of darkening depends upon the depth to which the roots of the prairie grasses have extended, and is usually from 12 to 18 inches, being greatest in the more humid sections and poorest drained places.

A dark color is popularly considered as an indication of productiveness and, in general, this is true. Attention, however, must always be given to the cause of the dark color, although in most soils it may usually be taken as indicative of the presence of humus in considerable quantity and in the most beneficial form. As humus is one of the most beneficial soil constituents, the Prairie soils are in general of high productiveness.

The Prairie soils embrace a great stretch of country, extending northward from the Gulf coast of Texas into Canada. They cover a very large percentage of western and southern Minnesota, northern and central Illinois, northern and western Missouri, Iowa, North Dakota, South Dakota, Nebraska, Kansas, western Oklahoma, the northern, central, and Gulf coast regions of Texas, with smaller areas in Louisiana, Mississippi, Alabama, Arkansas, Indiana, Wisconsin, and some other States. Much of eastern New Mexico, Colorado, Wyoming, and Montana represent a transition from these soils to those of the arid region.

An examination of the precipitation map of the United States will show that most of this region has a precipitation of from 15 to 35 inches. The general eastern boundary of the Prairie soils does not follow very closely the line of 35 inches of precipitation, owing primarily to differences in the nature of the underlying formations, although topography has had much influence also. In Missouri and Illinois the line runs in a north-of-east direction, almost coinciding with the precipitation line of 40 inches. After reaching Indiana, however, it turns rather sharply to the northwest, leaves nearly all of Wisconsin to the right and passes near St. Paul in Minnesota, although Wisconsin has less rainfall than Illinois and northern Minnesota as little as eastern Nebraska. The less calcareous and more sandy nature of the glacial material, combined with a morainic topography, do not give as favorable conditions for humus accumulation as do the more level and heavier soils of Illinois and other sections where the line swings so far east.

One of the most interesting and instructive occurrences of Prairie soils is in Alabama and Mississippi. Here the soils are derived from the Selma chalk, and although the annual precipitation is between 50 and 55 inches, a sufficient percentage of lime is present to give them a dark color. The limiting of these prairies to this very calcareous formation is one of the most striking examples and strongest proofs of a relation between lime and the dark color.

The general location of the Prairie soils is shown upon the soil map, but there are many small areas, especially near the boundary of the Timbered soils, which could not be indicated. Sometimes small areas occur far within the timbered regions, the most striking example being that in Alabama and Mississippi just noted.

SOILS FROM CRYSTALLINE ROCKS.

So far as known, practically no areas of Dark Prairie soils derived from crystalline rocks occur in the United States. These rocks do not seem to be favorable to their formation. Near Tishomingo, Okla., a few small areas have been noted, but it is probable that the soil here has been derived in part from limestone, although the granite lies immediately underneath.

SOILS FROM SANDSTONES AND SHALES.

This group includes all Dark-colored Prairie soils formed from the weathering of sandstones and shales. The material composing these rocks was carried into the sea or other bodies of water and later consolidated, only to be again uplifted and converted into soil. The character of this material depends upon the kind of rock from which it came as well as the conditions under which the rock was broken down. In general it may be stated that the more arid the region from which the material came, the larger the amount of soluble matter and the greater the percentage of other minerals than quartz. The attrition during transportation tended to wear out the least refractory minerals, while the chemical action of the water dissolved those more easily soluble. The particles were also assorted, the finer ones being deposited in quiet waters and the coarser ones left where the currents were strongest. These different factors, combined with others which have been active during the transformation from rock to soil, give opportunity for a wide variation in the character of the soils derived from sandstones and shales.

Owing to the influence of these various factors, several different series of soils have been found. Among these the following are the most important in the United States: The Morton, Pierre, Oswego, Summit, Bates, Vernon, and Kirkland series. On the map the Oswego, Summit, Bates, and probably other series could not be shown separately, and these are included in the Kansas group, while the Vernon, Kirkland, and doubtless other series are shown as the Oklahoma group.

MORTON SERIES.

The Morton series includes the dark grayish-brown soils with light-gray to pale-yellow calcareous subsoils. In the more typically semi-arid portions the quantity of humus decreases and the color becomes more a yellowish brown, grading into the arid soils. The subsoils are usually very high in lime, sometimes almost white from its presence.

The soils of the Morton series very closely resemble the Williams soils of the glacial formation, and in the absence of glacial bowlders it is often difficult to distinguish between them. This is doubtless due to the nature of the material composing the sandstone and shales from which the Morton soils have been derived. They have been formed principally from sandstone and shales of later Cretaceous age, chiefly the Laramie. The material composing these rocks was doubtless brought from the more arid regions to the west, where the original rocks were broken down largely through mechanical agencies, and therefore the material composing them resembles in character the glacial material which was ground up by the mechanical action of the ice. An examination of the sand shows it to contain a relatively large amount of minerals other than quartz. Being formed from disintegrated rather than decomposed rock material, the soils of both series have many similarities.

The most common class or texture in the Morton series is the silty loam to silt loam, while the fine sandy loam is next in extent. Only very small areas of stony loam, sand, clay loam, and clay have been encountered. A peculiar condition consisting of bare spots with a compact soil, locally called "gumbo flats," is a feature of the areas where the Morton soils occur.

The Morton soils are found chiefly in southwestern North Dakota, eastern Montana, and Wyoming, and northwestern South Dakota.

The topography is that of a gently rolling plain in which streams have carved out channels with considerable broken land along them. Buttes, sometimes rising as high as 500 feet above the surrounding plain, are a rather common feature of the landscape.

PIERRE SERIES.

Stretching along the west side of the Missouri River in South Dakota and extending westward to and around the Black Hills, like the prongs of a great Y, is an area of dark to slate-colored clayey shales which give rise to the Pierre series. This series consists of dark-brown to yellowish-brown surface soils underlain by gray to yellowish-brown subsoils. The heavier or clay member predominates, causing the section where this series occurs to stand out in marked contrast to the surrounding country of lighter textured soils. The Pierre clay is extremely sticky and is locally known as "gumbo." It occurs in quite large areas and constitutes one of the most extensive developments of heavy soils in the United States. Considerable areas of loam, silt loam, and silty clay loam also occur. The soils are derived from the Pierre and Graneros shales, principally the former, but some of those of lighter texture have probably been influenced by later deposits.

KANSAS GROUP.

In central and eastern Kansas, western Missouri, and northeastern Oklahoma the Carboniferous and Cretaceous shales form the surface rock and give rise to several series of soils different from either of the two already described. These have been included in the Kansas group. They consist principally of silt loam and silty clay loams with compact "tight" silty clay or clay subsoils. Over the greater proportion of the area covered there is a very distinct line of demarcation between the surface soils and the subsoil, and this is one of the chief characteristics of this group. This is least in evidence in central Kansas, but very pronounced in the southeastern part of the State.

It so happens that the rocks to the southeast are not only older, thus subjecting them to leaching for a longer period, but are also in a region of greater rainfall. In addition, it seems that the material composing the rocks in the central part of the State has been brought from more arid regions and subjected to less attrition and leaching in the processes of deposition and degeneration. Some beds of shales are more calcareous than others, and where this is the case the soils are darker in color and more productive. In the extreme southeastern part of Kansas the Cherokee shales give a light-colored soil, which is really more like the Timbered than the Prairie soils, although originally prairie. It closely resembles the loess soil (Marion silt loam) of southern Illinois, while the dark-gray soil (Oswego silt loam) is very much like the loess soil (Putnam silt loam) in northern Missouri and southern Iowa, as well as the Crowley silt loam of Arkansas and Louisiana.

Three series have been recognized in the Kansas group: First, the Oswego, with gray to dark-gray, rather floury surface soils and very heavy impervious mottled-gray or yellowish subsoils; second, the Summit series, with dark-gray to black soils and heavy mottled subsoils, derived from calcareous shales; and third, the Bates series of dark grayish brown soils, with porous yellowish subsoils.

OKLAHOMA GROUP.

The rocks from which the soils of all the above series are derived are gray, light brown, yellowish, or sometimes black, with almost a total absence of red, and the soils are characterized by a general similarity in color, but in south-central Kansas, western Oklahoma, and north-central Texas occurs a large area of generally red sandstones and shales, commonly known geologically as the Red Beds, which give rise to a group of soils of strikingly different color. These rocks are known to underlie a large proportion of the Great Plains and in addition to the area mentioned have, through uplift and erosion, been exposed along the eastern front of the Rocky Mountains and in the Black Hills. They usually contain beds of gypsum and are sometimes called gypsiferous Red Beds.

In some cases the immediate surface soil is a decided red and it varies from this to almost black. Sometimes the subsoils are not very red, but the deeper subsoils are practically always so. Upon this difference in color it is possible to separate the soils into at least two series, the Vernon and the Kirkland.

The Vernon series consists of reddish-brown to red soils with red subsoils. In texture they are principally fine sandy and silty loams with smaller areas of sand and clay. The structure in both soil and subsoil is loose and this makes them easily eroded, and deep gullies are a characteristic feature.

The Kirkland series has dark-brown soils with brown or yellowish-brown subsoils grading into red within a few feet of the surface. The texture is generally heavier than in the Vernon series, silt loams and silty clay loams predominating, and the structure of the subsoils is closer and less porous.

SOILS FROM LIMESTONES.

Limestones are not so extensive or important in the prairie as in the timbered region. The contrast between the soils of this and other formations is not so marked because practically all the Prairie soils are calcareous. The line of separation between the limestone soils and those derived from the unconsolidated calcareous deposits of the Gulf Coastal Plain is very arbitrary, as the material from which some of the latter soils is derived might be classed as a soft limestone.

The principal development occurs in the country west of Fort Worth, Waco, and San Antonio, Tex., but narrow bands are found in other sections, especially in central and eastern Kansas and west central Missouri, where thin beds of limestone alternate with the shales. The latter areas can only be shown in a detailed survey, but those in Texas are sufficiently extensive to be indicated on the accompanying map.

Not very much study has been made of these soils. The principal types so far observed are included in the Crawford series, which consist of dark or chocolate brown soils with reddish subsoils. Only the heavier classes of the series are present, the silty clay loam and clay being most common. The areas are generally characterized by frequent outcrop of the limestone and in the more broken areas stones are quite numerous on the surface, while the rock in many places is only a short distance below.

In central Kansas the limestone layers which occur in the Benton group give rise to the Benton series which has almost white and very calcareous subsoils. The areas are small, the surface rather broken, causing the white subsoils to be often exposed.

SOILS FROM ICE-LAID MATERIAL (GLACIAL).

One of the most important groups of Prairie soils includes those derived from deposits of drift laid down by the great continental ice sheet. This material consists of a great variety of rocks ground up by the action of the ice and mingled in a very heterogeneous mass. The general movement of the ice was from the north and much of the material has therefore been transported far south of where the rocks are found in place. As the rocks have been broken down by mechanical action and have since undergone little alteration, the particles are usually sharp and angular and consist, especially in the sand, of a relatively large percentage of other minerals than quartz. There has also been little assorting of the particles by water action, so that a great variation in size, from large bowlders to the finest clay, is often represented. Owing to this commingling by the ice and the small amount of decomposition which has since taken place, no true clay soils are formed from the glacial drift. Little washing down and out of the finer particles has been effected and, therefore, little difference in texture of soil and subsoil exists, 75 samples giving an average of 15.9 per cent of clay in the soil and 19.2 per cent in the subsoil.

The glacial Prairie soils are high in humus, the amount being greatest in the more humid portions and in those of heaviest texture and in areas of level topography and poor drainage. In passing westward to the semiarid regions the percentage, as well as the depth to which the organic matter extends, decreases.

The color is dark grayish brown to black, depending upon the amount of organic matter present. The subsoils are much lighter in color and are usually a pale yellow, gray, or light brown.

In the more humid portions quite a little leaching has taken place, but generally the soils are fairly well supplied with lime, and many will effervesce freely with acid, especially in the subsoils. In western North Dakota and Montana the amount of lime is much larger, and the subsoils here are almost white from its presence. While this greater amount here is due in part to the less leaching under semiarid conditions, there was doubtless more in the original material also, as the rocks, which were ground up by ice in this section, had likewise been subjected to less lixiviation. This difference has been deemed sufficient to justify the separation of the soils into two series—the Carrington[1] and the Williams. The former includes the soils which have the least lime and other soluble material, but a rather larger amount of humus.

One other striking feature of the glacial Prairie soils is the relatively large percentage of loams and the absence of true clays. Nothing heavier than a clay loam has been encountered, while the percentage of sands and sandy loams is not very large. This is due, of course, to the method of formation. Where the drift has been modified by water action or was laid down largely by this agency, sandy and gravelly soils are usually formed, but the area where this has taken place is relatively small, much smaller than in the glaciated Timbered soils.

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[1] In nearly all the Soil Survey reports these soils were mapped as Marshall.

The surface features are those of a rolling prairie, with somewhat broken country along the streams and sometimes billowy ridges where the ice deposited its load in terminal moraines. In some sections, especially in areas of later glaciation, lakes form a pleasing feature of the landscape.

SOILS FROM WIND-LAID MATERIAL (ÆOLIAN).

IOWAN OR LOESSIAL GROUP.

Usually associated with and in many respects closely resembling the glacial Prairie soils are those formed from the loess. Mineralogically and chemically, the material is very much the same, consisting in both cases of ice-ground rock débris. In the case of the loess, however, there has been an assorting and redistributing of the material by the action of wind and water.

The origin of the loess has been a very puzzling problem, one which has provoked a great deal of discussion. Some attribute its formation to water action, others to wind, while still others believe both agencies were concerned. Most geologists now agree that the last is most probably true. From personal observations in practically all sections where it is found in this country, the writer believes that it represents rock material broken down by the ice, assorted by water and in most cases distributed by wind.

It is not intended to go into a discussion of this subject here, for this has been done by other writers, but there is one point which does not appear to have been sufficiently emphasized, to which attention might be directed, and that is the influence of the seasons.. During the summer the streams flowing out of the ice-covered regions must have been greatly swollen and consequently flooded all the lower lands along them and deposited the silts washed out of the drift. As colder weather came these floods subsided, leaving the silt, without any vegetative covering, exposed to the wind, which swept it upon the adjoining uplands. This process was repeated each year and supplied a sufficient amount of material to cover large areas of the uplands. Evidence of this is seen in the widening of the belt of "bluff" loess along the Mississippi in Illinois opposite the larger bottoms.

The loessial Prairie soils are most extensively developed in central and western Illinois, eastern, southern, and western Iowa, northern Missouri, eastern and southern Nebraska, and northeastern and northwestern Kansas. Smaller areas are found in Indiana, Wisconsin, Minnesota, and the Dakotas.

Owing to the great uniformity in the size of the particles, the loessial Prairie soils are all silt loams. They are usually extremely uniform in character over large areas, so that it is possible to show types even on a small-scaled map. Three main types have been recognized—the Marshall silt loam, the Putnam silt loam, and the Colby silt loam.

The Marshall silt loam is one of the most extensive, most uniform, and most productive soils in the United States. It consists of a dark grayish-brown to black rather heavy silt loam about 18 inches deep, underlain by a pale yellowish, often slightly mottled, porous silt loam subsoil. In northeast Kansas and eastern Nebraska the subsoil is slightly heavier than elsewhere, owing probably to longer weathering as the result of greater age. It is much more extensively developed than either of the other types, covering a very large percentage of central and northwestern Illinois, parts of Iowa, especially the western, northwestern Missouri, northeastern Kansas, eastern Nebraska, with a small development in some other sections.

In southern Iowa, northern Missouri, and to a much less extent in some parts of southern Illinois, a different kind of loessial Prairie soil occurs; in fact, it is so different that there is some doubt as to whether it should be classed as a loessial soil. This has been called the Putnam silt loam.[1] It consists of a dark-gray silt loam with stiff, impervious, brown to drab mottled silty clay subsoil. A white silt layer is often present between soil and subsoil. This type closely resembles the Oswego silt loam derived from shale and the Crowley silt loam of the Gulf group derived from unconsolidated marine deposits.

Being formed from a pebbleless layer over the glacial material, it is classed with the loess. The peculiar nature of this material is probably due in part to the character of the rock débris, which here constitutes the loess, and in part to weathering as a result of long exposure to these agencies. In Illinois it is clearly due to a thin deposit of later loess over the older loess giving rise to the Marion silt loam. Much of the country where it occurs has drainage well established and the streams have cut through into the underlying glacial drift, which here gives rise to the soils of the Shelby series.

In southwestern Nebraska, northwestern Kansas, and eastern Colorado the loess extends westward into the semiarid region, and the difference in climatic conditions has produced sufficient difference in the soil to necessitate its separation here into the Colby silt loam. The surface soil resembles the Marshall silt loam, but is not so deep, nor so dark in color, is lower in humus but higher in lime. The chief distinction, however, is in the subsoil, the Colby silt loam being very calcareous and mealy because the material has undergone practically no weathering. This type really represents a transition toward the Arid soils.

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[1] Mapped in earlier soil surveys as Shelby silt loam.

SOILS FROM WATER-LAID MATERIAL (SEDIMENTARY).

Over a considerable proportion of the prairie region the surface formations consist of unconsolidated deposits formed through the action of water. While the material has been deposited by water, the soils differ from those found in the river bottoms in that they have been derived from the underlying material through the processes of weathering instead of being laid down as actual soils.

In the northern portion of the prairie region these deposits consist principally of lacustrine sediments, in the Great Plains section of old alluvial fans or débris aprons, and in the Coastal Plain of marine sediments. Because of the difference in the character of the material, the soils have been divided into three groups, the Red River Valley group, the Plains group, and the Gulf group.

RED RIVER VALLEY GROUP (LACUSTRINE).

Lakes are of very frequent occurrence in the glacial region, especially in sections where drainage is still immature. During the melting and retreat of the ice these lakes were not only much more numerous but covered much larger areas. Glacial material was carried into them and deposited as lacustrine sediments. Many have since become drained and from these deposits have been formed the Red River group of glacial-lacustrine soils.

These soils are closely related to the glacial Prairie soils, the difference being due largely to the assorting of the sediments by water rather than to any marked dissimilarity in the character of material. There is usually much less heterogeneity in the size of the particles and some very heavy clays occur in this formation, while they are entirely absent in the glacial. The topography is generally much more level; drainage is therefore poorer and the amount of humus greater.

The soils contain a large amount of organic matter, have a decided black color, and are very calcareous, especially in the subsoils. Except where incoming streams have formed sandy deltas, the greater proportion of the valley soils are of heavy texture, consisting of silt loam, silty clay, and clay. Most of the soils have been included in the Fargo series. Around the border of the valley very little material was deposited and the principal action of the lake consisted in smoothing the surface, and here are somewhat different soils. It is often possible here to bore through the lacustrine deposits into the underlying drift.

While the Red River Valley in eastern North Dakota and western Minnesota contains the most extensive development of these soils, they are found in smaller areas scattered throughout the glacial prairie region from Indiana westward.

PLAINS GROUP (AGGRADATION).

Throughout a large proportion of the Great Plains region south of the Black Hills the surface material consists of slightly consolidated deposits of Tertiary and Quarternary age. These deposits are characterized by a light almost white color and usually by a very large amount of lime. In the northern extension they are distinctly stratified, as may be seen in the "Big Bad Lands" of South Dakota, but farther south they are made up of irregular beds of gravel, sand, silt, and clay. The stratification in the older, more northern extension gives undoubted evidence of deposition in water, probably lakes, but the central and southern portion represents a great débris apron which has been spread over the plains through the action of streams. As a result of tilting or a change in climate, these eastward flowing streams were unable to carry their load of sediments and therefore filled up their channels and sought new ones. The coarser material was dropped where the currents were strongest, while the finer particles were deposited in more quiet interstream areas. In this manner a great series of aggradation deposits was built up, from which the plains group of soils has been derived.

Owing to the subhumid to semiarid conditions under which the soils have been formed from these deposits, little leaching has taken place. The zone of weathering has not extended much below 2 feet, being deeper toward the more humid eastern portion and shallower toward the drier western portion. The amount of humus is also greatest toward the east and the soils therefore darker.

Several different series can be recognized, among which the Rosebud, Richfield, Greensburg, Pratt, and Amarillo are the most important.

The Rosebud series consists of dark-gray to brown surface soils, with light-colored, almost white, very calcareous subsoils. One of the most characteristic features of this series is the almost white or pale flesh color of the deeper subsoil. Because of the ease with which this material erodes, the more hilly areas especially are dotted with bare white spots, and in extreme cases large areas of "Bad Lands" have been formed.

This series is formed chiefly from the White River and Arikaree formations of the Tertiary and occurs principally in southwestern South Dakota and western Nebraska. The former is generally silty and gives rise to the silt loam, which is the most important member of the series, or to occasional areas of silty clay loam and clay. The fine sandy loam covers considerable areas, especially where the Arikaree formation constitutes the surface.

The surface soils of the Richfield series are very much like those of the Rosebud, but the subsoils are more of a pale yellow or gray color. They occur principally in southwest Kansas and adjoining portions of other States. The principal type is the silt loam, which covers large uniform stretches, but considerable areas of sandy loams and silty clay loam are also found. The silty clay loam covers nearly all of Morton County, Kans., extending southward into the Panhandle of Texas.

As the formations which give rise to the Richfield series extend eastward into Kansas they become less calcareous, and have been more deeply weathered. Where this condition exists the soils contain more humus and are included in the Greensburg series, of which the silt loam is the only member of any importance. The most eastward extension and the oldest formations of the Tertiary in Kansas are only slightly calcareous and have a reddish tinge or color. These deposits have given rise to the Pratt series, which is characterized by dark or chocolate brown soils with reddish subsoils. Considerable areas of the sand; coarse sandy and gravelly loam; loam, and silt loam are found. The cause of the reddish color in this section is not entirely clear, but since the Red Beds underlie a large proportion, it seems probable that they have contributed a sufficient amount of material to produce this effect.

Principally on the High Plains in northwest Texas and the adjoining portions of Oklahoma and New Mexico occur the soils of the Amarillo series. This series consists of chocolate-brown to reddish-brown soils with reddish-brown to red subsoils, grading usually at less than 3 feet into an almost white or pinkish white very calcareous substratum. This calcareous substratum constitutes the most obvious difference between the Pratt and Amarillo series. The former, however, is hardly as red as the latter, especially in the sandy members. The series consists of sands, sandy loams, loam, and silty clay loam. The last is by far the most extensive, covering practically all of the Llano Estacado, or Staked Plains, as well as large areas of the High Plains north of the Canadian River. The sandy soils are found principally in the latter locality and are well developed around Dalhart, Tex.

In the case of the Amarillo soils the red color has apparently been developed in weathering. The occurrence of these reddish soils in this section is probably due to a reworking and admixture in the Tertiary deposits of material from the Red Beds. An examination of a geological map will show that these beds form the surface over a considerable area to the west, through which the Canadian River flows, but similar conditions are not found northward in the Cimarron and Arkansas drainage. It seems very probable, therefore, that material was washed from these Red Beds and transported eastward by the Canadian River to form a part of the deposits from which the Amarillo soils have been derived and that the reddish color is due to this cause.

GULF GROUP (MARINE).

In the Gulf Coastal Plain, particularly in Texas, occurs a series of unconsolidated or slightly consolidated calcareous clays, marls, and chalks, ranging in age from Upper Cretaceous to Pleistocene. These deposits give rise to another very important group of soils to which the name Gulf is applied.

The group may be divided into several series, the two most extensive and characteristic being the Houston and the Victoria. Where the calcareous deposits, from which these have been derived, grade into the Timbered soils some transitional series occur but these are of limited extent.

The soils of the Houston and Victoria series are very similar in character, and the separation is based largely upon topography, the former being rolling, while the latter is almost a dead level. The Houston series is situated in the inner portion of the Coastal Plain and the Victoria in the level coast country.

The most characteristic member of both series is the black clay or " black waxy land," so called because of its very sticky nature. The Houston black clay covers quite a large stretch of country, extending almost continuously from east of Paris, Tex., to beyond San Antonio. The Victoria clay occupies large disconnected areas in the coast country between Houston and Kingsville, Tex.

These black clays are very much like the Fargo clay of the Red River Valley group. One interesting feature of these clays, especially in the less humid southwestern extension, is the pitted surface on account of which they are often called " hog-wallow land." These depressions are seldom more than a foot deep and 3 or 4 feet across and are due to deep intersecting cracks, which allow the surface material to drop in, causing the formation of saucer-shaped hollows.

In some places the texture becomes lighter and areas of loam occur. The Houston fine sandy loam is of very limited extent, but the Victoria covers rather large areas.

In Alabama and Mississippi occur two belts of calcareous deposits which give rise to the Houston clay. While this soil is very dark in color compared to those with which it is associated, it is not so black as the Houston black clay. The difference is in part due to greater erosion under the heavy rainfall in the more eastern States.

Coming eastward from Texas into Louisiana, the coastal deposits become less calcareous, and although some prairies occur the soils are not so dark in color and the subsoils are more impervious. They represent a transition toward the Light-colored Timbered soils and in fact, the areas on the may really include a considerable percentage of Timbered soils. The texture here is also more silty, owing probably to an admixture of loessial material brought down by the Mississippi River when these deposits were laid down. One of the most important soils is the Crowley silt loam, areas of which occur in southern Louisiana and in Prairie and Lonoke Counties, Ark. Others have been mapped as Edna and Lake Charles fine sandy loam and loam. A characteristic of these last soils is the presence of sand mounds.

ALLUVIAL SOILS.

Along all the streams in the prairie regions, and also along those which have come from these regions, occur strips of alluvial soils which have been deposited during periods of overflow. The alluvial soils include what are popularly known as bottom lands. While they are very widely distributed, they usually occur in such narrow strips that only a few of the largest can be shown on the map. The most extensive development is found along the Mississippi River from the mouth of the Ohio to the Gulf.

Although part of the soils in this area have a light color and contain a relatively small percentage of humus, in general the color of the soils is dark gray to black, depending a good deal upon the texture. Where this is sandy, the color is usually not so dark as in the heavier soils, owing to the more favorable condition for the accumulation of humus in the latter. There is usually very little change in color with depth because the material was laid down as actual soil and therefore contains much humus several feet below the surface.

An exception to the almost black color of the alluvial soils of the prairie regions is found along those streams which run through the Permian Red Beds, and have reddish-brown to red soils along them. The principal streams are the Canadian, Red, Brazos, and Colorado. So pronounced has been the influence of these Red Beds that the Miller soils, as these red soils are called, follow these streams all the way to their mouth. The Miller soils are very calcareous, contain a considerable quantity of humus and are exceedingly productive.

The texture of the alluvial soils depends primarily upon the velocity of the current at the time of deposition, but is also influenced by that of the surrounding uplands. For example, all the streams where the Houston black clay constitutes the uplands, have a heavy black clay (Trinity clay) along them, but where the upland is covered by the Marshall silt loam, as in much of Illinois, the bottoms also consist very largely of silt loam, although the streams have about the same fall in both cases. In general, however, it may be stated that the swifter the streams, the coarser and more variable the texture. The coarsest particles are always deposited nearest the banks of the stream, while the finer ones are carried into the quiet back waters. Clay being the only particles which will remain suspended in quiet water for any length of time, the heavy soils are usually found next to the uplands, while those along the immediate banks are nearly always sandy. Large streams like the Mississippi River never deposit soils of coarse texture because the velocity is not sufficient to carry particles much larger than fine sand. Such streams, however, are practically the only ones which deposit very fine sandy loams, the velocity being just about the rate to carry particles of this size (0.1 to 0.05 mm.)

Usually these bottom lands are timbered, but since the soil has come from the prairies and as most of that shown on the map has the characteristics of the Prairie soils, they are included with them.

LIGHT-COLORED TIMBERED SOILS.

The light-colored soils of the timbered region have certain characteristics which distinguish them from those of the two regions already described. The most striking of these are (1) a lower amount of readily soluble mineral matter, including the important constituent lime, and a consequent large percentage of silica; (2) a moderate amount of organic matter, but a low percentage of black humus; (3) generally light color; (4) shallow surface soil with rather marked line of separation, especially as regards texture, between this and the subsoil; (5) native vegetation generally timber; and (6) lower average productiveness.

The heavy precipitation that occurs in this region leaches out a large percentage of the soluble salts, so that the soils are comparatively low in these substances and generally nonalkaline or "acid" in character. So great is the amount of leaching which has taken place that even the soils derived from limestones are deficient in lime or at least give a nonalkaline reaction. Brown[1] shrowed this to be true of the limestone soils on the experiment farm at State College, Pa., and the failure of the soils in other sections to give the dark tint to the humus is, in view of the relation which has been shown to exist between lime and this color, very strong evidence of the nonalkaline nature of even the limestone soils throughout the timbered regions. This is especially true as regards the surface material where the decay of the organic matter by the formation of carbon dioxide greatly aids in the leaching out of the lime. This process has not gone on so rapidly in the subsoil which sometimes has sufficient lime to effervesce quite freely with acid.

Since quartz is the most refractory toward purely chemical agencies of all ordinary mineral constituents, and since decomposition processes are relatively much more pronounced in humid than in arid regions, the soils of the former are relatively high in silica. In the case of the sands this may be readily seen from an examination with the aid of the eye alone, the grains consisting very largely or almost entirely of quartz. This is especially true where the sands have undergone much abrasion as in the South Atlantic Coastal Plain and least so where crystalline rocks have been ground up by ice. In the former case the quartz may constitute as much as 99 per cent, as may be seen by reference to the table on page 90.

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[1] Annual Report Pennsylvania State College 1907–8, Part II, p. 45.

In the table on page 15 the amount of "soluble salts" in the humid soils, according to the electrolytic method, was 0.013 per cent as compared with 0.333 per cent in the arid region. This shows that a large amount of material has been carried away. According to Merrill[1] "among siliceous crystalline rocks, this loss, so far as shown by available analyses and calculations, rarely amounts to more than 50 per cent of the entire rock mass. Among calcareous rocks, on the other hand, it may in extreme cases, amount to even 99 per cent." The amount of " insoluble residue," as shown by Hilgard in the table quoted upon page 14, is for the humid soils 84.17 per cent while for the arid soils it is 69.16 per cent.

Not only are these soils relatively low in soluble material, including the very important constituent lime, but this fact has had a very profound influence upon the amount and character of the organic matter they contain, as has already been pointed out in connection with the Dark Prairie soils. The failure, however, of soil investigators to recognize the importance of this matter justifies further emphasis here. In fact, the subject is one which needs to be studied very carefully and furnishes a very fertile field for further investigations. Probably new methods will have to be devised before very great progress is made. A statement of some field observations may be of assistance in pointing out lines along which these studies should be undertaken.

A determination[2] of the amount of organic matter in the Light-colored Timbered soils and the Dark-colored Prairie soils does not always show as marked a difference as one would expect from the great dissimilarity in color. An average of 150 samples from each section showed 1.64 per cent in the former and 3.56 per cent in the latter, the average being 2.60 per cent. Forty-five of the Prairie soils fell below the average and 24 of the Timbered soils above. In some instances, the percentage in a light-colored soil[3] is greater than in a dark-colored one, and it is not always possible to get a definite idea of the color of the two soils from an analysis by the "wet combustion method."[1] If, however, Prairie soils are compared with Prairie soils and Timbered soils with Timbered soils, it is nearly always possible, from the color, to arrange them according to the content of organic matter. This would strongly indicate that the organic matter in the soils of the two regions is in a different form, although the exact nature of the difference has not yet been shown. That this difference has a very pronounced influence upon productivity is reflected in the popular association of a dark color with a fertile soil.

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[1] Rocks, Rock-weathering, and Soils, by George P. Merrill, p. 234.

[2] "The 'organic matter' * * * was determined by a wet combustion of a sample of soil with chromic acid and multiplying the carbon dioxide obtained by the conventional factor 0.471, proposed by Wolfe, van Bemmelin, and others." Field Operations of the Bureau of Soils, 1902, p. 130.

[3] An examination of a few of the most striking examples showed the presence of small pieces of charcoal in the light-colored soils, while others had a large amount of roots, bark, etc., which in these instances accounted for the high percentage of organic matter.

Where the soils are closely associated, especially where derived from identical material, the difference in color seems to correspond more nearly with difference in organic matter than when derived from different formations. The Marshall and Knox silt loams in Illinois[2] are both formed from loess, the former being prairie and dark colored and the latter timbered and very light colored. An average of 12 samples of the Marshall silt loam showed 3.14 per cent of organic matter, while 10 samples of the Knox silt loam gave only 1.34 per cent. In all cases, however, there is a very marked difference in the character of the organic matter, the Timbered soils apparently containing a much smaller percentage of humus.

The moderate amount and nature of the organic matter gives to the soils of the timbered region a light color, except where mineral coloring matter predominates or where a surface mold has been formed.· The most common colors are gray and light brown, with red coming in prominently in the South. In some cases, however, they become almost white, and when associated with almost black soils, as in the country near the boundary between the timbered and the prairie regions, stand out in striking contrast. The difference in color is of very great importance, because it not only indicates a difference in the amount and character of the organic matter, but the lighter color is associated with a leached condition.

While there are some exceptions, it is, nevertheless, generally true that the lighter colored, nonalkaline soils are favorable for timber growth, while the conditions which cause the accumulation of humus are unfavorable. Therefore, these light-colored soils were practically all originally timbered. This contrast between the native vegetation on these two great groups of soils is very characteristic and striking. In the border regions it has been noted that certain species of trees are seldom if ever found except upon the light-colored soils, while others may grow upon the dark soils. Among the former may be mentioned the oaks and among the latter the walnut and elm.

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[1] Grandeau proposed a method for differentiating the matiere noire or humus from other forms of organic matter and while this method is not entirely satisfactory, it is much better than the wet combustion, which simply shows the total amount of organic matter with no indication of the condition in which it exists in the soil.

[2] Soil surveys of Sangamon, Knox, Winnebago, and McLean Counties, Ill., by George N. Coffey and others, Field Operations, Bureau of Soils, 1903. Knox silt loam was mapped as Miami silt loam.

Probably the most conspicuous example of original prairie upon the light-colored soils is in southern Illinois on the type mapped[1] as the Marion silt loam. Most of this type consists of very level prairies with almost white, "acid" soils. The subsoil is very hard and impervious, making root penetration difficult, and this is probably one of the principal reasons why timber is not found upon a large percentage of it. Along the border zone other exceptions may be found and transition soils must be expected.

While some of the Timbered soils are very productive, they are in general of lower agricultural value for general farm crops than those of the prairie region, although much better adapted to early truck crops. This is due largely to the fact that the lower amount of humus decreases their moisture-holding capacity and therefore causes them to warm up much more rapidly in the spring.

From certain observations that have been made and from a comparison of the results of some experiments it seems very probable, if not indeed proved, that the varieties of some of our leading crops which do best on the Dark Prairie soils will not prove best suited to the Lighter-colored Timbered soils. It is possible here to give only one illustration.

The Turkey Red wheat is a standard variety in almost all the black prairie region. On these soils in Illinois it was found to stand first, or among the first, while on the light-colored loess soil in the southern part of the same State, on soils from crystalline rocks in North Carolina, on limestone soils in Pennsylvania, and on glaciated shales soils in Ohio it proved one of the poorest yielders.

SOILS FROM CRYSTALLINE ROCKS.

Under this heading are included all Timbered soils derived directly from crystalline rocks except the limestones and marbles. The principal area in the eastern United States begins in eastern Alabama and extends in a northeasterly direction slightly beyond Philadelphia. The same rocks continue into New England, but glaciation here gives rise to transported rather than residual soils. The eastward and seaward boundary is marked by the "fall line" which passes through or near the cities of Baltimore, Washington, Richmond, Raleigh, Columbia, Augusta, and Columbus. In its southern extension the western boundary practically coincides with the North Carolina-Tennessee line, while northward it follows the westward side of the Blue Ridge. This area practically includes all of the Piedmont Plateau, except the Triassic basins and bottom lands, as well as the eastern portion of the Appalachian Mountains.

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[1] Soil surveys of Clinton, St. Clair, and Clay Counties, Ill., Field Operations, Bureau of Soils, 1902.

A few small areas occur in Missouri, Oklahoma, and the Black Hills. The Rocky Mountains consist very largely of crystalline rocks, although not all are timbered, while other areas are found throughout the West, although very little study of the soils in these localities has been made.

The rocks belong to the two great groups, igneous and metamorphic. From the soil standpoint, however, these may be combined under the more general term of crystalline. These rocks were formed through the agency of heat and metamorphism, and the conditions to which they are now exposed are very dissimilar to those under which they had their origin. In general, therefore, it may be said that they are out of harmony with their surroundings and rather easily attacked by the agencies of weathering. They represent the oldest part of the continent and have been subjected to degenerating influences for a great length of time. In the ages that have elapsed since these rocks were exposed, doubtless many hundred feet of soil have been formed and washed away only to be renewed by further weathering of the rocks below, and this process will continue until the regions where they occur are reduced to base level.

One of the characteristics of soils derived from crystalline rocks is the angular shape of the particles, especially the sand, due, of course, to the absence of rounding by water action. As there is a great variety of crystalline rocks, many kinds of soil will be formed through their degeneration. It is not possible to give all the different varieties that occur, and only the most important will be considered. These distinctions are based more upon differences in the soils than in the rocks, for, although the former are largely dependent upon the latter, weathering has often extended to such depths that fresh specimens of the rocks are difficult to obtain, and the determination of their exact nature therefore impracticable, although differences in the soils are plainly evident.

In the northern Piedmont the rocks are largely granites, gneisses, and mica schists which have given rise to light-brown or yellowish-brown surface soils, with yellow or slightly reddish yellow porous, friable subsoils. They usually show a large percentage of mica, principally biotite. They have a granular, rather " loamy " structure, with little difference in texture between soil and subsoil. They apparently have more humus and lack the gray appearance of the nonred soils further south. A much greater proportion of loams and silt loams is also present. The percentage of silt is greater, and the contrast between soil and subsoil is much less, as may be seen from the table following.

Average amount of silt and clay in Northern and Southern Piedmont soils.

Region.	No types.	No samples.	Silt.		Clay.	
			Soil.	Subsoil.	Soil.	Subsoil.
Northern	5	39	48	43	22	21
Southern	10	141	33	28	17	40

The principal soils are included in the Chester series, of which the Chester loam is the most extensive. Large areas of this type have been mapped in the Albemarle and Leesburg areas of Virginia, Cecil and Harford Counties, Md., and Montgomery and Chester Counties, Pa.[1]

From central Virginia southward occurs a series of hydro-mica schists or slates, which give soils quite different from those of the Chester series. The surface soils are light gray to almost white and very siliceous. They run together and become more compact than the Chester soils, and organic matter disappears very rapidly and almost entirely. This seems to be characteristic of many soils derived from magnesian rocks. The subsoils are heavy, plastic clays with a distinct greasy feel, due to the sericite mica present. The color of the subsoil varies from yellow to red, and upon this difference they are separated into two series, the Louisa series being characterized by red and the York series by yellow subsoils.[2]

Throughout the central and southern Piedmont the greater proportion of the country is covered by soils of the Cecil series, consisting of grayish-brown to red soils, with moderately friable and porous, though rather heavy red clay subsoils. One of the characteristic features of this red clay is the large content of sharp sand and the small percentage of silt. An average of 80 samples showed 35 per cent of sand, 20 per cent of silt, and 45 per cent of clay.

The Cecil series is derived from granite, gneisses, and schists, and from gabbro diabase and other basic igneous rocks. The granites and gneisses include those in which the more basic ferruginous minerals are relatively most abundant. The dominant types in the series are the sandy loam, clay loam, and clay. The small amount of silt precludes the formation of loam and silt loam members. The sandy loam is formed exclusively from the granites, gneisses, and schists. The clay is also formed from these rocks, but in addition is derived from basic igneous rocks, such as gabbro and diabase, which never give the sandy loam. The formation of the clay from the more acidic rocks has been due to the washing off of the sandy surface layer and the exposure of the red clay which constitutes the subsoil. In some cases it may be due to an increase of the basic minerals in the granitoid rocks. The deep weathering makes the determination of this point very difficult.

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[1] See Reports of Bureau of Soils for these areas. Except in Pennsylvania it was mapped as Cecil loam.

[2] These soils have been mapped as Cecil fine sandy loam and Cecil silt loam in nearly all the soil survey reports of the Bureau of Soils, but are now placed in separate series, because of these differences which are inherited from the parent rock.

The very acidic or binary granites weather into soils with yellow rather than red subsoils, and these are included in the Durham series, the coarse sandy loam and sandy loam being the principal members. The surface soils are light gray and very siliceous, being composed very largely of crystalline quartz. They are very much less extensive and considerably less productive than the Cecil soils.

One of the most distinctive groups of soils in the Piedmont Plateau consists of types with rather dark gray or brown surface soils, containing a very large percentage of iron concretions, underlain by very impervious, plastic, waxy, dingy yellow clay subsoils. This subsoil is the most characteristic feature and has given rise to the local name of "beeswax land." The native growth of blackjack oak causes the term "blackjack land" to be applied also. These soils are included in the Iredell series. The subsoil swells and shrinks in wetting and drying, causing the formation of many cracks. This marked change in volume is possibly due to the presence of large amounts of "colloidal" clay. A sample shaken in water for several hours and placed in a long tube gave a gelatinous deposit upon the sides as well as the bottom of the tube, while the Cecil clay did not. This subsoil is so extremely impervious that sufficient water can hardly pass through it to cause the decomposition of the underlying rock, which is usually found within less than 3 feet of the surface.

The rocks are principally diorite and diabase and appear as intrusions through the granites, gneisses, etc. An aplite granite is often associated with the basic rock, and the change from one to the other is very frequent. In Alamance County, N. C., alternating bands of these rocks, sometimes only a few inches in thickness, are very common.

Although very much the same kinds of rocks occur in the Blue Ridge Mountains as in the Piedmont Plateau, the marked difference in topography has caused considerable variation in the processes of soil formation, and therefore the soils are somewhat dissimilar. Here erosion has much more nearly kept pace with degeneration, the rock is nearer the surface, the subsoils not so deeply weathered, and the color generally a less pronounced red. In other words, the regolith in the mountains is thinner and not so thoroughly decomposed.[1] In some of the intermountain plateaus, like that around Hendersonville, N. C., the zone of weathering is deeper and the soils are really more like those of the Piedmont Plateau than those of the surrounding mountains.

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[1] Compare the mineralogical composition of the Cecil and Porters soils in table on p. 88.

Owing to the mountainous and nonagricultural character of so large a proportion of the country, the soils have not been studied in as much detail as in the more thickly settled Piedmont Plateau.

Most of the soils are included in the Porters series, but further and closer study will doubtless show the necessity of recognizing others. So far as observed they are most nearly like the Cecil soils of the Piedmont Plateau.

While practically no true loams are found in the Piedmont, a loam and a black loam occur in the mountains. The latter is the result of the accumulation of organic matter in the coves of the mountains and has no counterpart in the Piedmont. The loam seems to be due to a less thorough decomposition of the rock in the mountainous region.

SOILS FROM SANDSTONES AND SHALES.

The soils formed from sandstones and shales constitute one of the most extensively developed formations in the timbered region. They occur in two principal areas. The first and largest one begins in north-central Alabama and extends northward to New York, its northern boundary being formed by the southern limit of glaciation. It includes nearly all of the Allegheny Plateau and in shape is almost exactly the reverse of the adjoining eastern area formed from crystalline rocks, being widest in the north with a panhandle to the south. Along the eastern border, especially to the south, it is cut by numerous limestone valleys.

Another rather large area occurs in central and western Arkansas and eastern Oklahoma. In the latter State, especially near the central and northeastern part, the Light-colored Timbered soils and the Prairie soils are rather badly mixed and could be separated only by a detailed survey. Similarly small areas are found in Missouri, especially along the contact of the limestone with the sandstone and shale soils of the prairies, the more broken sections having light-colored soils, although the more level areas are darker.

A considerable area occurs in west-central Kentucky and a duplicate of this is found across the Ohio in southern Indiana, although much of the latter is covered by the loess.

Others are found in the Triassic basins of the Piedmont Plateau from North Carolina northward, the largest development being in Pennsylvania.

The rocks consist of mechanical deposits which were eroded from the older rocks, carried into the sea, consolidated through heat and pressure, uplifted to form the land, and through the agencies of weathering converted into soil. The various processes which this material has undergone have removed the more easily abraded and readily soluble parts and combined with the leaching, which is taking place at the present time, makes these soils generally very siliceous in character, much more so than those from the same kind of rocks in the prairie region. The sandstones, especially, are very resistant to weathering and have often given rise to rocky ridges or mountains with really little soil upon them. These are very prominent along the west side of the Appalachian Mountains and in parts of Arkansas and eastern Oklahoma.

In texture, the soils are principally fine sandy loams and silt loams, the latter being the more common. The fine sandy loams are derived from the sandstones, while the silt loams come from the shales. In some cases, however, as in the Panhandle of West Virginia, a silt loam is formed from fine-grained sandstone. A shale, however, never gives a fine sandy loam, although a sandy shale may give a loam. Silt loams derived from sandstones are generally poorer soils than those from shales. In many cases, principally in the older rocks, fragments of sandstone or shale constitute a large percentage of the soil mass, and here stony or shale loams are formed. Over much of the country the rock is only a few feet below the surface, and outcrops are not infrequent. While some of these soils are very productive and many areas of good farming land are found, in general, they are rather low in agricultural value.

Not all sandstones and shales are alike in lithological and chemical composition, and this variation causes differences in the character of the soils. The most extensively developed soils in the Allegheny Plateau are gray to yellow brown in color, while the subsoils are usually some shade of yellow. Most of these soils are included in the Dekalb series. In general, they are a little more granular in structure and not quite so gray in color in northern areas as farther south, but the difference is not so great as in the soils in the Piedmont Plateau, Coastal Plain or the limestone valleys, where the variation is too great to permit correlation as the same types. In general, the relative percentage of sandy loams is larger in the southern portion. The Dekalb soils most closely resemble in character the Norfolk soils of the Coastal Plain.

Interbedded with the lighter-colored rocks, which give the Dekalb soils, are purplish-red sandstones and shales which weather into brown and red soils with red subsoils, constituting the Upshur series. The color is not a bright red like the Cecil soils, but more of a purplish or Indian red, very similar to the Penn soils of the Triassic basins. In general, there is a larger percentage of clay in the Upshur than in the Dekalb series, the Upshur clay being the most characteristic member of the series. The Upshur soils are very limited in area, especially in the southern extension of the Allegheny Plateau.

In the Triassic basins included in the Northern Piedmont, red rocks predominate, and these have given rise to the soils of the Penn series. These soils have the same Indian-red color as the Upshur, to which they are very closely related. The surface here is much less broken, the rocks have weathered more deeply, and the country is much better adapted to agriculture. The soils are characteristically silty, the texture being principally a loam, with a large percentage of silt, or a true silt loam.

Associated with the red soils are those derived from gray and yellowish rather than red rocks These give light-brown or yellowish-brown soils with pale-yellow or yellowish-gray subsoils and are included in the Lansdale series, of which the silt loam is the principal member.

The Penn and Lansdale soils are practically confined to the northern Piedmont Plateau. A considerable development of the former may be seen as far south as Orange, Va., and small areas even farther, but, in general, the Triassic soils in the southern Piedmont are quite different from those in the northern. This may be due in part to differences in weathering under somewhat different climatic conditions, but is much more largely the result of a change in the character of the rock. In the northern Piedmont the Triassic basins are surrounded largely by limestones and shales, and the formations in them are made up principally of wash from these rocks. In the southern Piedmont, however, the material came almost entirely from the crystalline rocks and is somewhat different. In the Richmond basin, for example, the Triassic rocks are arkose in character and give gray sandy soils with yellow subsoils, very much like the Durham soils derived directly from granite.

In the Triassic basin in North Carolina, the soils are not very dissimilar, except the deeper subsoils are heavier and more plastic and show more of the purplish red color. In the deeper cuts still more red is seen, while in some cases the red comes to the surface.

In texture the soils of the northern and southern Triassic areas show quite marked contrasts, the former being very largely loams and silt loams while the latter are predominately sandy loams. It is probable that the more sandy texture has aided in leaching out the red color of the more southern soils through the action of organic matter. They are of considerably lower agricultural value than those in the northern section.

SOILS FROM LIMESTONES.

Limestones are composed essentially of calcium carbonate, with which occur various impurities. Through solution, which readily takes place in water containing carbonic acid, the carbonate is removed leaving behind the more resistant materials, occurring in connection with it, to form the soil. In some cases limestones contain as much as 98 per cent calcium carbonate, and it would therefore require many feet of rock to form one foot of soil.

While the original rocks contain a very large percentage of lime, it does not necessarily follow that the soils derived from them are calcareous. A limestone soil and a calcareous soil are not synonymous terms. The former refers to soils derived from limestones; the latter to soil in which there is actually a considerable content of lime. There are many calcareous soils not derived from limestones and many soils derived from limestones that are not calcareous, the lime in the latter case having been leached out. While the amount of lime in soils derived from limestones is usually greater than in those from other kinds of rocks, it is seldom sufficient in humid regions to give the dark color to the humus. In fact, most of these soils require the addition of lime in order to give an alkaline reaction. In limestone regions it is not an uncommon sight to see farmers burning the limestone, which is found a few feet below the surface, and applying the lime to the fields.

The reason for the low lime content of these soils is found in the excessive leaching which has taken place. The rocks are usually rather hard and a long period of time is necessary to weather them into soil. They are all of pre-Cretaceous age and have been subjected to leaching for many thousands of years. Therefore not enough lime is left to make the surface soils truly alkaline and organic matter has not accumulated in sufficient amount and in the proper form to give them a dark color.

One rather striking fact in regard to limestone soils is the almost total absence of sandy soils. The texture is practically always as fine or finer than a loam and usually there is very little sand present, silt and clay constituting almost the entire mass. This is the result of the method of formation of the stone, clear water being essential to the life of the organisms to which most limestones owe their origin.

The limestone soils may be divided into two general groups; (1) those formed from the purer, noncherty limestones or Shenandoah group, and (2) those derived from the cherty or siliceous limestones or Ozark group. The former usually occur as valleys or basins, and are generally of high agricultural value, while the latter form plateaus or ridges and are held in much lower esteem. The general location of the two groups is shown on the map, but it was impossible in some cases to separate them on so small a scale. In fact, many small bands or areas of the limestone soils could not be indicated, especially throughout the series of valleys lying along the eastern boundary of the Allegheny Plateau.

While the above groups and series include the principal limestone soils, smaller areas differing very distinctly from any of these, are occasionally encountered. The Bangor limestone in northern Alabama, eastern Tennessee, and Kentucky, for example, gives rise to a yellowish-brown to yellow clay loam or clay overlying a sticky yellow clay.

SHENANDOAH GROUP.

The soils from the purer limestones may be divided into the yellow-brown soils with yellowish to reddish-yellow subsoils and the deep red soils with intense red subsoils.

The majority of the yellow-brown limestone soils are included in the Hagerstown series. The soils are light brown or yellowish brown in color and of a rather granular, loamy structure. There is a considerable amount of humus present, apparently much more than in the soils formed from the more siliceous limestones. The immediate subsoil is usually yellow, but becomes redder with depth, and at 3 feet is often a reddish yellow or sometimes even a red with only a slightly yellowish tinge. In general, the heavier the texture, the redder the subsoil. The texture is predominantly silty, although some small areas of clay occur. The Hagerstown soils are among the most productive in the country.

The principal areas of the Hagerstown soils occur in the limestone valleys of Virginia and Pennsylvania and in the interior basins of Kentucky and Tennessee. Very small areas have also been seen in West Virginia, Alabama, Missouri, and Arkansas. Going southward from Pennsylvania the character of the limestone changes, becoming more dolomitic and cherty until in southwest Virginia the Shenandoah limestone grades into the Knox dolomite. A gradual change can also be noticed in the soils, the color becoming less brown and more gray southward, the structure less granular, the percentage of chert noticeably greater, the topography more hilly.

In the Allegheny plateau thin strata of limestone are often interbedded with the shales and these give rise to narrow bands of limestone soils which resemble in many characteristics those of the Hagerstown series. In some cases the materials from the shale and from the limestone have been mixed. This is usually true where the latter occurs on hillsides, but often the limestone caps the hills, and here true limestone soils are formed. Owing to differences in topography the agricultural value is not as high as in the case of the Hagerstown soils. These soils are placed in the Brooke series.

In northern Alabama, northwestern Georgia, and to a less extent in Tennessee, the pure limestones and dolomites give rise to intensely red soils which are included in the Decatur series. Typical developments may be seen around Decatur, Tuscumbia, and Talladega, Ala.

The Maryville limestone in eastern Tennessee has, so far as seen, always given rise to these blood-red soils. The red color is probably due to an accumulation of iron in the weathering of the relatively pure limestones. The texture is principally silt loam and clay loam with some small areas of clay. These soils are very strong, fertile, and highly esteemed.

OZARK GROUP.

In striking contrast to the above soils are those formed from the cherty and siliceous limestones. The surface soils of the latter are gray in color, much more siliceous and stony in character, contain a less amount of lime and humus, are less granular in structure, generally much more hilly in topography, and of decidedly lower agricultural value. The subsoils are yellowish to reddish yellow, often changing to yellowish red or red in the lower portions. Most of these soils are included in the Clarksville series.

There are two principal areas of these soils, one occupying the Highland Rim region of Kentucky and Tennessee, the other the Ozark region of Missouri and northern Arkansas. Smaller areas occur in eastern Tennessee and northern Alabama.

In the latter areas the soils, which are formed principally from the Knox dolomite and Fort Payne chert, usually have a little more sand than in the other areas and in texture are loams, although the percentage of silt is rather high. The percentage of chert here is not so great, especially where derived from the Knox dolomite, as in the two larger areas.

In the Highland Rim and the Ozarks the surface soil is all very silty, but there is a great variation in the amount of chert present. In some places fragments of chert literally cover the surface, while in others very few or none are found. In general, the more level areas are the least stony.

The reason for the great variation in stone content is not entirely clear. The stoneless areas may represent places where there was very little chert in the limestones or where the silt has been left from the shales which formerly overlaid the limestones in many sections. In the former case its occurrence upon the more level areas could be accounted for by the more rapid wearing down of the surface where no chert was present, just as a layer of shale overlying a hard stratum of sandstone tends to form a table-land. The irregular distribution of the chert would explain the failure to form distinct table-lands, as is the case in sandstone and shale formations. On the other hand, if the silt represents a residue from former overlying shales, it would naturally be found more upon the level areas where erosion had been least. The similarity of the soil in the cherty and noncherty areas, the doubtful occurrence of a previous covering of shales in some areas, at least, where the stones are not present, the almost total absence of sand (an average of 35 samples shows only 16 per cent of sand of all grades), which would be more likely to remain than silt, and the irregular elevation at which these silty areas are found, all seem to indicate that their presence is due to the variation in the character of the original rock and not to a residue of silt left from a former overlying deposit of shale.

SOILS FROM WATER-LAID MATERIAL.

The unconsolidated formations, which have been laid down through the action of water, cover extensive areas in the timbered portion of the United States. In the glaciated section they consist of lacustrine deposits composed largely of reworked glacial material, but in the Coastal Plains they represent marine or aggradation deposits, principally the former. Accordingly, the soils are divided into two principal groups—the Atlantic Group and the Ontario Group.

ATLANTIC GROUP.

In the Atlantic and Gulf Coastal Plains and in a few detached areas farther inland occurs a great series of unconsolidated formations which give rise to one of the most extensive soils divisions of the United States. The material composing these formations was eroded from the older land areas to the north and northwest, transported by streams and deposited in the sea, in estuaries and bays, or as aggradation deposits upon older formations which had previously been elevated above sea level. Doubtless the rocks from which this material came had been subjected to leaching for a great length of time and much of the soluble material had been removed. This fact, combined with the decomposition and attrition which took place during the transportation and final deposition of the material and the further leaching since the elevation of the Coastal Plains above sea level, has resulted in the removal of many of the easily abraded and more soluble minerals and has given to the soils in general a very siliceous nature.

Differences in the character of the material which has been brought down by the streams and in the amount of reworking or wave action to which this material has been subjected have produced considerable variation in different sections. In the Chesapeake Bay region and northward the streams came either from a glacial section farther north or from limestone valleys, and in general the deposits are less siliceous than farther south. The sand here consists of a larger proportion of other minerals than quartz and is not so clean, i. e., more fine material adheres to it, seeming to indicate less reworking by wave action. In some places, however, especially on the lower elevations near the coast and the larger streams and estuaries, the material has apparently been reworked and resembles that found farther south. From Virginia southward to Florida, especially in the level country covered by the Columbia formation, the deposits are most siliceous, some of the sands containing as high as 99 per cent of silica.[1] Wave action has apparently had much influence here and it is also probable that much of the material came from the older formations of the Coastal Plain and had previously been subjected to much attrition. In some cases the material has been so abraded by wave action that very little is left except pure white quartz, and the soil might then be truly designated as "worn out."

Going westward in Alabama, Mississippi, and Louisiana deposits are in general somewhat less siliceous, owing probably to the fact that part of the material came from the limestone valleys while other portions were brought from the north by the Mississippi. Some of the younger formations show a mingling of loessial material. The change becomes very evident in Texas. Going southwestward the streams come from progressively more arid regions and the material brought down by them therefore contains more and more soluble material and a larger percentage of feldspar and other minerals than quartz.

As a whole, the soils of this group are predominantly sandy, although some very heavy clays are found. These heavier areas most often occur in the Cretaceous formations near the inner border of the Coastal Plain or associated with calcareous formations like the Selma chalk. The Potomac clays of Maryland, the lignitic clay of Alabama and Mississippi, and the Yegua clays of Texas give the largest areas of heavy soils, while the Columbia formation has the largest proportion of deep sands.

In general, the sandiest soils occur along the streams and in the country nearest the coast. The sounds, bays, and estuaries, which indent the Atlantic coast, principally south of the Chesapeake Bay, and the streams which enter them are nearly always bordered by deep sands. In eastern North Carolina, especially along the Cape Fear, Neuse, and Tar Rivers, the sands often cover practically all the country lying at an elevation of less than 20 to 25 feet above tide level, while the higher areas are sandy loams. Rather similar conditions exist in South Carolina and Georgia and to a less extent in Florida, Alabama, and Mississippi. In the last two States, the deep sands do not extend so far inland, while in Louisiana and Texas no such conditions exist, although a fringe of sand islands follows the coast from New England to the Rio Grande.

Not all of the deep sands occur near the coast and at low elevations, but some are located in the very opposite positions. In fact, a sandhill region is found near the inner border of the Coastal Plain. This region begins in North Carolina and extends through South Carolina and Georgia into Alabama. A similar belt has been observed just north of Crockett, Tex., which extends southwestward and may be seen about 15 or 20 miles southeast of San Antonio. These narrow bands of deep sands very much resemble old shore lines.

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[1] See Norfolk series in table of mineralogical analysis, p. 90.

A very large proportion of these formations consists of sandy clays which give rise to sandy surface soils, most often from 8 to 24 inches in depth, overlying sandy clay subsoils. Although this condition occurs practically throughout this division of the Coastal Plains, it is more prevalent in the section between Virginia and Florida. In Alabama, Mississippi, Louisiana, and Texas the subsoils often consist of heavy, plastic, impervious clays, but these are almost entirely absent in Virginia, North and South Carolina, Georgia, and Florida, while northward they are practically confined to a narrow strip near the inner border.

One of the most striking features of the Atlantic group of soils is the very small percentage of silt, causing the almost total absence of loams and silt loams. In the Chesapeake Bay region and northward silty soils are not uncommon, but from Virginia southward very few areas are encountered until the Mississippi drainage is reached and usually not in this section except where the soils are derived from formations younger than the loess, especially those formed from the Port Hudson and Grand Gulf. In other words, the silty soils in this group are practically confined to the northern portion of the Coastal Plain and to the Mississippi embayment.

There is a greater variety of colors in this division than in any other group in the United States. The surface soils range from white, gray, light, or yellowish brown to brown, reddish brown, and deep blood red. In some places the amount of organic matter increases and the color becomes darker and these soils grade into the Black Swamp or Prairie soils. The subsoils show even a greater variety of colors than the surface soils. This is due in part to the leaching out of the coloring matter in the surface material, but poor aeration has often caused mottlings, especially in the heavy clays.

In the northern Coastal Plains the majority of the surface soils are of a light or yellowish-brown color, while the subsoils are yellow to reddish yellow and are included in the Sassafras series. Usually beds of sand or gravel occur within a few feet of the surface and often outcrop as rather narrow bands along the stream slopes. The gravel is more common near the border of the Piedmont Plateau. The texture varies from beds of gravel through sands and sandy loams to loams and silt loams, the last closely resembling the loess of the Mississippi Valley. The sands are very restricted in extent and in fact hardly any true sand is found, most of that which occurs really being a loamy sand. The sandy loams are quite extensively developed as are also the loams and silt loams, the latter more widely than in almost any other section of the Coastal Plains. The explanation is probably found in the source of the material, this having come from the silty limestone and shale soils and from glacial deposits.

A very striking example of differences in soils formed from exactly the same material, but under different moisture conditions, occurs in this section. Where the surface is rolling or undulating the yellow-brown soils of the Sassafras series just described are found; where identically the same material has been subjected to intermittent wet and dry conditions, the soils have turned almost white, and where water stands practically all the year organic matter has accumulated in sufficient quantity to give the Black Swamp soils. The white soils are included in the Elkton series. They have a very small amount of humus, are close and compact in structure rather than granular, have mottled gray subsoils showing lack of aeration, and are apparently low in iron and lime, and on the whole of rather low productiveness.

Most soils when heated turn red as a result of the dehydration or higher oxidation of the iron, but a sample of the Elkton silt loam remained almost white even after heating to a red heat. A qualitative examination showed only a very small percentage of iron, this element having probably been leached out by the action of organic matter in solution. Where a considerable amount of lime is present, similar drainage conditions will not give the white soils.

The Elkton soils are not so extensive as the Sassafras and occur principally on the level divides between water courses. As sandy soils are usually too porous to hold water, the loams and silt loams are the principal types in the Elkton series.

Associated with the formations which give rise to the Sassafras and Elkton soils are deposits of greensand marl which weather into a yellow-brown sandy loam (Collington) underlain by a yellow or greenish-yellow sticky sandy loam or sandy clay at 30 to 40 inches. This grades into the greensand. Deposits of greensand are reported from many other sections of the Coastal Plains, but with the exception of small areas in some parts of Texas, they do not outcrop sufficiently to be mapped even in a detailed soil survey. Near Lufkin, Tex., and in Lee County in the same State a deep red clay has been formed from a greensand marl.

Throughout almost the entire timbered portion of the Coastal Plain occur extensive areas of gray soils with yellow subsoils, resembling in many characteristics the Sassafras soils which are confined to the region around and north of Chesapeake Bay. The majority of these are included in the Norfolk series.

From Virginia southward to Florida the Norfolk soils have their most extensive and most typical development. In the inner portion of the Coastal Plain in North Carolina they cover almost the entire country, but going seaward the surface becomes more level and Black Swamp soils alternate with them. This latter condition exists southward to Florida and to a less extent in southern Alabama and Mississippi. Beginning in South Carolina and extending through central and southwest Georgia into northwest Florida and thence westward to Texas, the Norfolk series occupies relatively a much smaller proportion of the country than in the section just referred to. In these latter sections, especially in Louisiana and Texas, the soils are not exactly similar to those in the Atlantic Coastal Plains, while the surface features are also much more rolling.

The Norfolk soils consist very largely of sands and sandy loams, the latter usually having very sandy surface soils with yellow sandy clay subsoils. Practically no loams or silt loams are found, the only areas seen being formed from the "yellow loam" in Alabama and Mississippi, which closely resembles the loess and probably represents an eastern extension of this formation mixed to some extent with other material. The Norfolk sands represent the most extensive occurrence of very sandy soils in the United States. They are found as a border around the sounds and along the streams, especially in the central and south Atlantic sections and to a less extent on the divides between the streams. The latter, however, are more often occupied by the sandy loams. In general the texture of this sand is finer nearer the coast. In some inner sections, particularly in Georgia and Alabama, deposits of coarse sand and even gravel are found. The sands are practically confined to the Post Tertiary formations, but the sandy loams are derived from both Tertiary and Quarternary deposits.

Some reference has already been made to differences in the soils of the northern and southern Coastal Plains, but it seems best to bring these out more clearly and to show reasons for this variation. As the Sassafras series is the dominant series in the former and the Norfolk in the latter (as well as the most nearly equivalent), this can probably be best done by contrasting these two series.

In the Sassafras series a larger amount of silt is present, the sand grains have more fine particles adhering to them, a relatively higher percentage of other minerals than quartz are found, the deeper subsoils are usually sandy or gravelly, the surface soil has a yellow-brown rather than a dead-gray color, is more granular in structure, apparently contains a greater amount of humus and lime, and is in general more productive.

Several factors have combined to cause these differences. In the first place some of the material comprising the Sassafras came from the glacial region, where the rocks were ground up by the ice, as is proven by the presence of striated bowlders on the eastern shore of Maryland. In the second place, most of the larger streams, like the

Potomac and the Susquehanna, drain extensive areas of limestone, sandstone, and shale formations, while all the streams southward to Alabama, except the James, flow from areas of crystalline rocks. Only a few small headwater tributaries of the latter stream come from limestone and shale formations. Coming from the limestone valleys the northern streams have brought down more lime and also more silt than those of the south. In the third place, the soils from the Piedmont Plateau, as already pointed out, are different in its northern extension. And in the last place, the climate of the two sections is not entirely similar and this has doubtless had an effect upon the character of the soil. The last condition has probably had less influence than any of the others.

The division between the northern and southern Coastal Plains soils is just south of the Potomac River and Chesapeake Bay. There is really no well-defined boundary, but rather a grading one into the other. The southern soils extend farther northward along the inner border than along the outer. In fact, some of the soils in northeastern North Carolina show the influence of a mixing of the northern material, although very little effect is seen even north of Richmond, which is situated on the edge of the Piedmont. In some sections near the coast where the Sassafras material has evidently been reworked by wave action there are small areas, even as far north as New Jersey, which have soils very much like those farther south.

In southern Georgia and Alabama and possibly elsewhere occur gray soils with yellow subsoils, which closely resemble the Norfolk but have some characteristic differences. They are locally called "pimply land" from the iron concretions or cementations which are a constant and characteristic feature. These are really not true concretions, but are rather cementations of the sand in concretionary form. While yellow, the subsoils are of a slightly different color from the Norfolk, resembling somewhat cottonseed meal. The agricultural value of these soils, which are included in the Tifton series, is higher than of the Norfolk.

In northwest Alabama and northeast Mississippi the Coastal Plains deposits lap up over the sandstones and shales of the southern Allegheny Plateau, and both the topography and the soil material have been influenced thereby. The country has a hilly and broken surface and the soils are rather gravelly, have many iron crusts in them, and are of low agricultural value. The surface soil is gray, while the subsoil is yellow to reddish yellow. These are included in the Guin series, the principal type being the Guin fine sandy loam.

Beginning in South Carolina and extending southwestward into Florida and westward into Texas, a large proportion of the timbered Coastal Plains is covered by deposits of red to orange or yellow sandy clays, most of which have been included geologically in the Lafayette formation. Some geologists have held that this formation was of marine origin, but it is now believed to be a fluvial or aggradation deposit. The character of the material itself, its occurrence as a mantle over nearly all of the older deposits of the Coastal Plains, the variation in elevation even within short distances, the irregular stratification or lack of stratification, the almost total absence of fossils, all seem to support the theory of an aggradation deposit.

The soils from this formation usually have a gray surface, but in some places it is red. Where the gray soils have a yellow subsoil they are included in the Norfolk series, but where the subsoil is red they are called Orangeburg. In case the red color comes to the surface and is of a darker, deeper, or more of a blood-red shade, the soils are included in the Greenville series.

The cause of the difference in color between the red and the yellow has been investigated by several workers who have not reached an agreement or offered an entirely satisfactory explanation. The writer selected 22 samples of red and yellow soils from different parts of the United States and a study of the cause of the difference was made by Robinson.[1] He found that in every case except one the red soils showed a larger percentage of iron than the yellow, provided soils of similar texture were compared. This would seem to show that the difference is usually due to a variation in the thickness of the film of iron oxide coating the soil grains.

The deposition of these red sandy clays probably followed a period of long stability or gradual sinking of the land surface during which the rocks were deeply weathered, forming a thick regolith of red material. Comparatively rapid changes of level, especially an uplifting movement, greatly accelerated erosion. The deep-red regolith was carried down the hillsides into the streams and spread out by them farther seaward. The material looks very much as if the Cecil soils of the Piedmont Plateau had been simply transported and redeposited without much change in character. The material does not seem to have been subjected to much, if any, wave action. In almost all instances where it has been reworked into later formations, especially those of undoubted marine origin, the red has been washed out or changed to yellow. Few or no red soils are found in sections of the Coastal Plain covered by post-Tertiary formations. For some reason, not clearly understood, the Lafayette formation north of South Carolina is seldom, if ever, red.

As the Orangeburg soils resemble so closely the Cecil, it is easy to account for their origin in the section of the Coastal Plain adjoining the Piedmont Plateau, but it is more difficult elsewhere, especially west of the Mississippi River. In northern Louisiana the Orangeburg soils are quite similar to those farther east, but west of the Red River some change is noted, probably due to the fact that the streams come from a region of less rainfall as well as different geological formations. The surface soils are hardly as gray, not quite as siliceous, and contain more iron concretions, while the subsoils are not so typical red sandy clays, but are rather heavier and contain slightly more silt.

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[1] The Color of Soils, by W. O. Robinson, Bul. 79, Bureau of Soils, 1911. This bulletin contains a summary and discussion of the results of various investigations.

The Greenville soils are closely associated with the Orangeburg. They differ from them in having reddish brown to red instead of gray surface soils and deep blood-red subsoils. The color is very similar to the red (Decatur) limestone soils, but the texture is not so silty. They are, however, somewhat more loamy than the Orangeburg, have a less rolling topography, and are also more productive.

The cause of the intense red color and its persistence, especially in the surface soil is not understood. It is possible that this material is more calcareous and that the lime neutralizes to some extent the organic acids and prevents the leaching out of the iron. The presence of limestone only a few feet below the surface in some places and of greensand marl in others would lend color to this theory.

The Orangeburg and Greenville soils are very largely sandy loams. The surface soils, however, are very light sandy loams or sands with a very sharp change in texture when the subsoils are reached, particularly in case of the Orangeburg. The depth of the sandy covering varies from a few inches to nearly 3 feet, depending upon the favorableness of conditions for the removal of the finer particles.

In general, the older geological formations of the timbered portions of the Coastal Plains consist of heavier clays than the younger ones. These formations, and to a much less extent the later ones, have given rise to soils characterized by heavy, impervious, and plastic, rather than porous and sandy-clay, subsoils. The surface soils are usually gray in color and sandy in texture, the fine sandy loams predominating, while the subsoils are nearly always mottled, owing to imperfect aeration. According to differences in the coloring of these clays, the soils have been divided into several series. Of these, the Susquehanna and the Lufkin are most extensively developed, the former including gray soils with mottled red plastic clay subsoils and the latter gray soils with mottled yellow and gray subsoils.

The Susquehanna soils are very extensively developed in Georgia, Alabama, Mississippi, Louisiana, and Texas. Practically none are found in Virginia and North and South Carolina, although a band occurs along the border of the Piedmont in Maryland. In other words, they are found in those sections which are not covered by the Lafayette or later formations.

One of the striking features of these soils is the marked difference and abrupt change in texture between the soil and subsoil in the sandy loams. For example, an average of 20 samples of the fine sandy loam, which is the most extensive type, showed 8 per cent of clay in the soil and 44 per cent in the subsoil. It seems that this is probably due in part, at least, to the former presence of a more sandy formation, possibly the Lafayette, overlying the heavier clays.

In the "flatwoods," or Lignitic clay, section of Alabama and Mississippi and in portions of Texas, especially where the Yegua clays constitute the underlying formation, occur the gray or mottled gray and yellow clays which form the subsoil of the Lufkin series. As regards plasticity and imperviousness, the Lufkin subsoils closely resemble the Susquehanna, the principal obvious difference being in the coloring. In general, however, the topography of the Lufkin soils is much more nearly level than the Susquehanna, which is often quite hilly.

Associated with the Selma chalk formation, which gives the black prairie belt in Alabama and Mississippi, are the gray to yellowish-brown soils and yellowish-brown to dingy-yellow subsoils constituting the Oktibbeha series. These are locally known as "post-oak prairies." The formation from which they are derived immediately overlies the Selma chalk and in the lower portion is quite calcareous. It probably represents a transition from the deep or quiet water conditions under which the Selma chalk was deposited to that of more agitated and turbid waters. Some of the lighter textured soils doubtless contain an admixture of material from later deposits.

Along the streams in many portions of the Coastal Plain, but more particularly in Alabama, occur a series of terraces or "second bottoms" upon which the soils differ in some respects from those of the adjacent uplands and might be considered as another group, although their extent is too limited to indicate on the map. These terraces were formed during Pleistocene time and in age are probably synchronous with the deposits in the level country bordering the coast, which is usually included in the Columbia. The material was deposited by the streams and was not subjected to the action of the waves. While this material was laid down by streams, the soils are distinctly different from those of the present flood plains, being much more like those of the uplands proper. This is due to their exposure to the agencies of weathering for many centuries. They should, therefore, be considered as soils derived from water-laid material rather than true alluvial soils. The principal series so far encountered are the Cahaba and Kalmia, the former consisting of brownish-gray soils with reddish-yellow to reddish-brown subsoils, and the latter of gray soils with mottled gray and yellow subsoils.

A number of other series are included in the Atlantic group of soils, but they are of much less importance and present no especial features of interest, so they will not be described in this paper.

ONTARIO OR LACUSTRINE GROUP.

During the melting and retreat of the ice from the northern part of the United States there were formed numerous lakes, many of which remain until the present time, although less extensive than formerly. Into these lakes material was carried by streams and a series of lacustrine deposits formed, from which soils have since been derived through the action of certain agencies and processes. The chief development of these deposits occurs around the Great Lakes, but smaller areas are scattered throughout the timbered glacial region.

Differences in the character of the material brought in by the stream have given rise to several series of light-colored soils, the most important being the Vergennes, Dunkirk, and the Superior.

The Vergennes series occurs on the terraces surrounding Lake Champlain, and is derived from the Champlain clays. The surface soils are gray to light brown, while the subsoils are drab to light gray, appearing almost white when turned up by the plow. The chief type is the clay, which covers about three times as great an area as all the other members of the series combined.

Where the material carried into the lakes consisted largely of wash from shales, with standstones and limestones, the Dunkirk series occurs. This series has light-gray to brown soils, with drab, gray, and mottled yellow subsoils. The Dunkirk series occurs principally around Lake Ontario, Lake Erie, and smaller lakes in New York and Ohio.

Around the southwestern end of Lake Superior and on the western side of Lake Michigan the lacustrine deposits are red instead of gray or yellowish, as is the case farther east. These red deposits give rise to the Superior series, of which the clay is most extensive.

SOILS FROM ICE-LAID MATERIAL (GLACIAL).

During Pleistocene time almost the entire northern portion of the United States was covered by a great continental ice sheet which, upon melting, left a mantle of heterogeneous material over the underlying formations. The line of the southern extension of this ice sheet touches the Atlantic coast about New York City, passes through northern New Jersey, northeastern Pennsylvania, and southern New York; thence turns southwestward through northwestern Pennsylvania and Ohio to Cincinnati, crosses the Mississippi River at St. Louis, follows along the west side of the Missouri River into Montana, runs just south of the Canadian boundary line across northern Idaho into Washington, extending farthest south in the Puget Sound region.

While practically all of the country north of this line is covered by glacial deposits, only small areas of the Light-colored Timbered soils occur south of a line drawn from about Lafayette, Ind., to St. Paul, Minn. Such developments as are found to the south generally occupy narrow strips near stream channels, while the more level divides have Dark-colored Prairie soils. West of the Rocky Mountains only a few small prairies occur, and most of the glacial soils here are forested.

As compared with the Prairie soils from ice-laid deposits, these timbered soils are much lighter in color, and lower in humus and lime, while the percentage of stony, gravelly, and sandy soils is very much greater. Large areas of these coarser textured soils occur, especially in Michigan, Wisconsin, and Minnesota, where the drift has been more or less assorted by water and the finer particles washed out, probably contributing to the formation of the loess. With the exception of western Ohio and central and northern Indiana, the topography is more hilly and morainic, kettle holes and billowy ridges being a rather constant feature. The drift is also thinner and its rock content consists of a much larger percentage of the underlying formation, so much so in places that some writers are inclined to treat the soils as residual rather than transported. This is especially true in New York and New England and in the extreme northwest. In the mountainous portion of these sections particularly the soil is very stony and areas where the ice swept off all the loose material, leaving the bare striated rock to form the surface, are not of infrequent occurrence.

As compared with the soils outside the glaciated region these soils consist of a more heterogeneous mixture of rock material, the size of the particles varying from that of bowlders to clay. The sand is composed of a larger percentage of other minerals than quartz and is not so clean.

The texture is practically never heavier than a clay loam, and except where water has assorted the material to some extent at least is not lighter than a heavy sandy loam. There is also very little difference between the texture of the surface soils and subsoils, an average of 120 samples of each showing 39 per cent of silt and 17 of clay in the soil and 41 per cent of silt and 21 per cent of clay in the subsoil, or a difference of only 6 per cent in the silt and clay combined, hardly enough to be perceptible were the quantity of organic matter and the structure the same. It is thus seen that the clay subsoils, which are so common in the warmer, more southern, latitudes, are usually wanting, doubtless owing to the less decomposition which has taken place in the glacial soils.

The color of the soils is usually some shade of gray or light brown, while that of the subsoils is most often gray to yellowish. A striking feature of these soils is the almost total absence of red or other brilliant colorings, which is the result of the predominance of mechanical disintegration over chemical decomposition in the breaking down of the rocks. The only examples of red glacial soils are where the coloring existed in the rocks which were ground up by the ice. Considerable areas exist in northeastern Pennsylvania and the adjoining portion of New York. In western Wisconsin and eastern Minnesota the till is slightly reddish, sufficiently so to be called the "red till." Some reddish soils have also been found in the Puget Sound region, but there is very little development in other sections than those mentioned.

Over much of the country covered by this group of soils it is possible to subdivide them according to the character of the rocks which predominate in the drift. In much of New England and the Adirondack region of New York, as well as in parts of Wisconsin and Minnesota and the extreme Northwest, the glacial material is composed largely of crystalline rocks. In the first areas these rocks really represent the northward extension of the crystalline rocks of the Piedmont Plateau and eastern Appalachian Mountains and the soils are therefore related to those found in these sections.

Variation in the character of these crystalline rocks has given rise to several series, the most extensive being the Gloucester and the Bangor. The Gloucester series consists largely of granitic material and is usually decidedly micaceous, principally biotite. In the Bangor series the mica is largely sericitic and the subsoils are grayer than in the Gloucester. In both series the stony sandy loams, stony loams, and loams are the principal types.

In northeastern Pennsylvania, southeastern New York, western Massachusetts and Vermont, and possibly in some other portions of New England occurs a series of slates and slaty shales, which have very largely determined the character of the drift and given rise to the Dutchess soils, among which the slate loam is the principal type.

In southern New York, northern and northwestern Pennsylvania, and northeastern Ohio the underlying rocks are largely shales, with some sandstones, which were ground up by the ice and give rise to the important Volusia series of soils. The texture is chiefly a silty loam to silt loam, although westward toward Cleveland, Ohio, it might be classed as a silty clay loam. The percentage of shale fragments is usually high, but decreases toward the west where the shales are softer. In parts of Michigan, Wisconsin, and Minnesota the deeper glacial deposits consist largely of sandstone and these soils have been included in the Coloma series.

In western Ohio, eastern, central, and northern Indiana, parts of Michigan, Wisconsin, and Minnesota, and to a less extent in other sections, the drift contains a large percentage of ground-up limestone. In Ohio and westward the drift is rather thick and many bowlders of igneous and metamorphic rocks are scattered over the surface. These soils are included in the Miami series, which is one of the most important series of glacial soils. In Ohio and Indiana the clay loam covers almost the entire section occupied by the Miami series, but elsewhere it is found in only small areas, the stony, gravelly, and sandy loams constituting the principal types. In eastern New York and New England the drift on the limestone is very thin and other series of soils are found, among which the Dover and the Nunda are the more important.

SOILS FROM WIND-LAID MATERIAL (ÆOLIAN).

In general it may be stated that in a humid region the æolian deposits are of less importance than in an arid, because the vegetative covering and the moist condition of the ground in the latter are not conducive to the movement of the material by the wind. Practically the only deposits of any depth being formed at the present time are those consisting of dune sand along the coast or around the border of lakes. During the glacial time, however, it seems that conditions were more favorable for the deposition of finer material and large stretches of country were covered with a mantle of silt, known as loess, largely through the action of the wind. The æolian soils of the timbered region may then be divided into the light-colored loess soils included in the Mississippi group, and Dunesand or Sandhill. The latter group is of practically no agricultural value and will not be discussed further.

MISSISSIPPI OR LOESSIAL GROUP.

As the loess is all very silty, no true series of loess soils exists, and the subdivision is really into types instead of series. Three principal types of light-colored loess soils have been encountered. These are the Knox silt loam,[1] the Memphis silt loam, and the Marion silt loam. The first two grade into each other and the difference is not marked, but the Marion is strikingly different. The Knox silt loam is a light-gray, sometimes almost white, or light-brown silt loam, while the Memphis silt loam is often of a pale-yellow color, does not contain quite as much clay, but more silt, and the deposit is usually much deeper. The Knox is confined to the upper Mississippi Valley, usually as strips of timbered lands bordering the streams; the Memphis to the middle and lower portions, principally on the east side of the river, although some outliers are found on the west side, as in Crowleys Ridge, Ark. In the country bordering the Ohio it is rather difficult to say with which type the loess soil should be correlated, although it is probably nearer the Memphis.

The Marion silt loam covers the greater part of 30 counties in southern Illinois, while some areas occur in southern Indiana and

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[1] Mapped in most reports of the Bureau of Soils as Miami silt loam.

Ohio. This type has a very light gray ashy surface soil, with generally a white subsurface layer changing abruptly at about 15 inches into a hard silty clay, locally called hardpan. It possesses the characteristics of the Russian podzol (under-ash). It is low in lime, and tests by the Vietch method show that an addition of 2,000 pounds of lime per acre is often necessary in order that the soil may give an alkaline reaction.

The reason for the low amount of lime is probably about as follows: The greater part of the underlying rocks in central Illinois are shales and sandstones, which had been subjected to leaching for a great length of time, when the ice moved southward over them, and therefore the lime, never very abundant, was carried away. The ice picked up this leached material which went into the composition of the loess, causing it to be low in lime. The level character of the surface allowed water to remain for some time after rains, causing an intermittent wet and dry condition. In the absence of sufficient lime to neutralize the acids formed, they attacked the iron and other compounds and caused them to be leached out or downward into the subsoil. Had lime been present, the soil would have been black.

In St. Clair, Ill., the Marion silt loam is undoubtedly derived from an older loess than the Memphis, many sections being seen where the latter material occurs as a distinct overlying layer.

BLACK SWAMP SOILS.

The Black Swamp soils are characterized by (1) a small amount of soluble mineral matter, (2) a large amount of organic matter, (3) a dark or black color, and (4) usually marked contrast between soil and subsoil. It is thus seen that they resemble the Prairie soils in some respects and the Light-colored Timbered soils in others. They might be regarded as forming a transition from the latter to muck and peat.

As these soils are confined to the humid region, they have been largely leached of the soluble mineral matter. They are low in lime and are therefore in an " acid " or nonalkaline condition. The organic matter in them is " sour " and apparently in a different form from the humus in the Dark-colored Prairie soils. In the latter case it seems to be an alteration product due to very thorough decomposition, while in these soils it is largely undecomposed. As soon as the soil is drained and aerated, the organic matter begins to decay more rapidly and in a comparatively few years almost entirely disappears. As the dark color is due to the presence of organic matter, the shade becomes lighter as the amount of this decreases.

The formation of these soils is due to the accumulation of organic matter under a superhumid soil condition. They are therefore formed in those sections where the precipitation is abundant and the surface is level or depressed, so that the water does not readily run off. It is also evident that an impervious subsoil will be favorable to their formation. The largest areas in the United States where these conditions exist are in the southeastern part, especially in the coastal section of the Carolinas, Georgia, and Florida. They occur, however, in smaller areas throughout the humid region.

Owing to the small areas in which these soils are found it is not practicable to make a separate group of them on the map. They occur almost entirely in that portion of the humid regions where the underlying formations consist of unconsolidated water-laid deposits, principally in the sections shown as the Atlantic and Ontario groups on the map. The principal soils are included in two series, the Portsmouth and the Clyde. The former occurs in the Atlantic group, principally in the level country from Virginia southward to Florida, while the latter occurs in the Ontario group, principally from Michigan eastward into New York. The Portsmouth has been formed from very much the same material as the Norfolk, the difference being due to poor drainage, which has resulted in the accumulation of organic matter and also chemical changes in the material, as is evidenced by the gray or mottled subsoil. The Clyde is derived from the same material as the Dunkirk, to which it bears the same relation that the Portsmouth does to the Norfolk.

ORGANIC SOILS.

This division includes soils composed very largely or almost entirely of organic matter. Owing, however, to the great influence of this material in determining the character of the soil the line of division between Organic and other soils can not be placed at 50 per cent as has been done by some investigators.[1] Although no study has been made to determine the exact percentage, it seems probable that it should be not more than 20 per cent and, in fact, if a soil contains more than 10 per cent it appears rather "mucky."

According to differences in the quantity and stage of decomposition of the vegetable matter, organic soils may be divided into muck and peat. The latter consists almost entirely of organic matter in a partially decomposed condition, the fibrous nature and vegetable origin of the material being usually quite evident. Muck has a larger percentage of mineral matter present, while decomposition has progressed so far that the fibrous structure is no longer discernible.

These Organic soils have been formed by the accumulation of the remains of various plants, spagnum moss being especially abundant in northern latitudes. They occur only where a superhumid condition retards the decay of the vegetable matter.

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[1] See the classification of soils given in "Terres Arables du Pas-de-Calais," by A. Pagnoul, 1894.

While deposits of peat and muck are found in many parts of the United States, the areas are usually small, so that they could not be indicated on the map. These areas are, however, very numerous in the northern portion of the United States where the topography left by the ice is especially favorable to their formation. A considerable development also occurs in the Atlantic and Gulf Coastal Plains where the surface is so level that water does not run off. Some areas occur even in the arid regions, where local drainage conditions are particularly favorable. An example may be seen near Stockton, Cal., and in other places in the Interior Valley.

Although all these areas are classed as muck or peat, there is undoubtedly a difference in the character of the material, which is sometimes expressed by the terms "sour" and "sweet." Where the associated soils are calcareous the Organic soils usually have considerable lime, but when this is not the case they are generally much benefited by liming. Coffee-colored water or material is indicative of a "sour" condition. In Illinois peat soils have shown marked response to potash fertilizer, but this may not prove true in all other sections.

MINERALOGICAL COMPOSITION OF SOME IMPORTANT SOIL SERIES.

In order to find out something in regard to the mineralogical composition of the soils which have been described in preceding pages, 25 important series were selected for mineralogical analysis.[1] Ten individual samples of the surface soils of each series were taken and a composite sample made from these. A separation of the sand, silt, and clay in each composite sample was then made by mechanical analysis, and the mineralogical composition of the sand and silt determined, the clay particles being too fine for a study of this character. The analysis included the determination of the percentage of all other minerals than quartz; the more abundant or characteristic minerals, and those less abundant or less characteristic. The results are given in the table on pages 87 to 91. Some of the most striking facts in the table have already been alluded to,[2] but it seems best to add further emphasis to some of them in this connection and to make other brief comments.

One will note at once the large percentage of other minerals than quartz in the arid soils as compared with the humid. It is true that some of the series from the crystalline rocks—particularly the Iredell, Chester, and Porters—have almost or quite as large a proportion, but there is a marked contrast in the minerals present. In the arid series the feldspars, including practically all the principal varieties, are abundant, while in the humid series, with the possible exception of orthoclase and microcline, they are rather accessory than characteristic, the chief minerals being hornblende, mica, pyroxene, and other basic varieties.

Of the major divisions of humid soils those from crystalline rocks show much the wider variation in the proportion of quartz, as well as in the character of the minerals present, which is to be expected. In some of the series orthoclase feldspar occurs in considerable quantity, indicating a good supply of potash. In others this mineral does not appear at all; in some (Iredell) the percentage of femic minerals is very high; in others calcic varieties predominate. Apatite is found in only one of the five series, suggesting a low phosphorus content. The Louisa series is mineralogically and agriculturally among the poorest series of the country.

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[1] The analytical work was done by Mr. W. J. McCaughey, formerly connected with the laboratories of this bureau, but now with the Ohio State University. These examinations were made by oil-immersion methods and the details of the examination will be found in a forthcoming bulletin of this bureau on the Microscopic Determination of Soil-Forming Minerals. It has not been found possible to examine the clay separate for mineral determination, as these particles are too small to lend themselves to this method. These examinations therefore indicate the composition of the soil, disregarding the clay separate.

[2] These analyses were not received until the other part of this paper was written, and so it was not possible to make much use of them there without entirely recasting the material, which it did not seem desirable to do.

Mineralogical analyses of important soils.

ARID SOILS.

Soil series.	Minerals other than quartz in—		Abundant and characteristic minerals in—		Less abundant or accessory minerals in—		Remarks.
	Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
	Per cent.	*Per cent.*					
Fresno	30-50	50-70	Hornblende, feldspars; orthoclase, plagioclase,[1] albite to andesine.	Biotite, hornblende	Epidote, biotite, zircon	Plagioclase, muscovite, pyroxene, epidote, tourmaline, orthoclase, apatite, zircon.	Distinctly angular. Characterized by high content of feldspars, mostly alkalic type, generally unaltered. Plagioclase weathered. Traces of diatoms in silt.
Yakima	50	50 est.	Augite, volcanic glass, plagioclase mostly andesine and labradorite, oligoclase.	Biotite, hornblende, pyroxene, muscovite, diatoms.	Epidote, biotite, phlogopite, apatite, serpentine (iddingsite), hypersthene orthoclase.	Plagioclase, orthoclase, apatite, epidote, iddingsite (serpentine).	Grains fairly well rounded to angular. Volcanic glass has inclusion of microlites and trichites. Some feldspars zonally developed. Much devitrified glass.
San Joaquin	20-25	15-20	Hornblende, plagioclase, albite, oligoclase, and andesine, orthoclase.	Biotite, epidote	Epidote, zircon, titanite, microcline, biotite, basaltic hornblende, muscovite.	Muscovite, orthoclase, hornblende, chlorite, tourmaline, zircon, rutile.	Characterized by large amount of hornblende and presence of acid plagioclase. Also quartz grains well rounded.

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[1] Plagioclase is so listed when the variety could not be determined and in some cases the feldspars could only be listed as such or simply as feldspar residues. The same is true of some other minerals.

Mineralogical analyses of important soils—Continued.

SOILS FROM CRYSTALLINE ROCKS.

Soil series.	Minerals other than quartz in—		Abundant and characteristic minerals in—		Less abundant or accessory minerals in—		Remarks.
	Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
	Per cent.	*Per cent.*					
Cecil	3-5	10	Zircon, sillimanite, rutile, microcline, plagioclase, biotite.	Sillimanite, chlorite, muscovite, orthoclase.	Epidote, muscovite	Garnet, hornblende, epidote, tourmaline.	Stretched and undulatory quartzes. Grains mostly angular but not prominently so.
Chester	25	30	Hornblende, biotite	Hornblende, biotite, muscovite.	Microcline, andesine, tourmaline, magnetite, garnet, chlorite, actinolite, rutile, epidote, muscovite, sillimanite.	Epidote, tourmaline, sillimanite.	Magnetite inclosing rutile needles.
Louisa	1-2	5-8		Muscovite (sericite), epidote, sillimanite.	Epidote, zircon, tourmaline, biotite, hornblende, rutile.	Biotite, tourmaline, zircon, rutile.	Grains mostly angular, some rounded; zircons well rounded. Mostly carries inclusions showing secondary origin.
Iredell	30+	40 (est.)	Pyroxene, augite, hornblende, epidote.	Pyroxene, biotite, epidote, hornblende.	Feldspar: Orthoclase, microcline, plagioclase, andesine, labradorite, apatite, ilmenite, biotite, magnetite.	Hornblende, chlorite, magnetite.	Quartz mostly angular, sharply so. Characterized by high percentage of femics.
Porters	13	25-30	Hornblende, orthoclase, microcline (unaltered).	Biotite, hornblende, muscovite.	Muscovite, biotite, garnet, epidote.	Pyroxene, epidote, zircon, chlorite, plagioclase, microcline, rutile.	Angular, a few well rounded. Minerals show but slight alteration.

SOILS FROM SANDSTONES AND SHALES.

Light-colored Timbered soils:							
Penn	5	20	Orthoclase, much altered, hematite.	Decomposed feldspar, epidote.	Epidote, microcline, muscovite, chlorite.	Plagioclase, pyroxene, zircon, biotite, sillimanite, tourmaline, muscovite, magnetite, chlorite.	Many secondary quartz grains, inclosing iron oxide. Hematite as inclusions and as covering of grains in silt.
Dekalb	2-3	8	Orthoclase, very much altered.	Tourmaline	Microcline, zircon, chlorite.	Chlorite, hornblende, muscovite, biotite, epidote, rutile, zircon.	Grains fairly well rounded. Quartz crystals. In silt quartz crystals-carrying calcite.
Dark-colored Prairie soils:							
Morton	25+	30+	Calcite, orthoclase, feldspars abundant and altered.	Epidote, hornblende, calcite, orthoclase, altered and fresh.	Microcline, plagioclase, oligoclase, epidote, chlorite, hornblende, tourmaline, apatite, zircon.	Tourmaline, muscovite, apatite, zircon, biotite, chlorite.	Feldspar altered and much rounded and also angular and fresh, suggesting admixture of material.
Summit	50-60	60 est.	Feldspar, plagioclase, oligoclase, labradorite, microcline, orthoclase.	Epidote, hornblende, feldspars, orthoclase.	Apatite, epidote, garnet, pyroxene, zircon, fluorite.	Rutile, chlorite, muscovite, tourmaline, biotite, zircon, sillimanite.	Quartz grains not much worn. Primary and secondary about equal. High feldspar content. Much organic matter in silt.

SOILS FROM LIMESTONES.

Hagerstown	5-8	8-10	Secondary quartz crystals, microcline, weathered orthoclase.	Altered feldspar	Tourmaline, zircon, chlorite, muscovite, rutile, fluorite.	Hornblende muscovite, epidote, tourmaline, chlorite, rutile, zircon, microcline.	Angular grains predominate over rounded grains 3:2. Quartz grains mostly secondary. Rather unusual amount of feldspar.
Clarksville	2-3	3-5	Secondary quartz crystals, feldspar highly altered.		Tourmaline, rutile, zircon, hornblende garnet, chlorite, biotite, partly altered to chlorite.	Tourmaline, muscovite, epidote, chlorite, zircon, hornblende, microcline.	Many grains fairly well rounded, others angular. Many primary quartz.
Decatur	4 est.	5-7	Many secondary quartz crystals carrying inclusions of calcite.		Tourmaline, zircon, rutile.	Tourmaline, muscovite, biotite, rutile, hornblende, zircon.	Angular, fairly well rounded to well-rounded grains, 2:1:1, characacterized by abundant quartz crystals. Quartz grains in the silt carry calcite.

Mineralogical analyses of important soils—Continued.

SOILS FROM WATER-LAID MATERIAL.

Soil series.	Minerals other than quartz in—		Abundant and characteristic minerals in—		Less abundant or accessory minerals in—		Remarks.
	Sand.	Silt.	Sand.	Silt.	Sand.	Silt.	
	Per cent.	*Per cent.*					
Sassafras	12	18–20		Biotite, hornblende	Hornblende, biotite, muscovite, apatite, chlorite, microcline, epidote, rutile, tourmaline, hypersthene, weathered orthoclase.	Muscovite, orthoclase, epidote, acid plagioclase, microcline, staurolite, zircon, tourmaline.	Angular grains predominate 2:1, complex mixture of varied mineralogical composition.
Norfolk	1 or less.	3–5			Microcline, apatite, zircon, tourmaline.	Microcline, orthoclase (altered), biotite. chlorite, hornblende, zircon, tourmaline, rutile, sillimanite, epidote.	Well-rounded quartz grains and zircons. Many quartz grains secondary carrying inclusions of iron oxide.
Greenville	3–5	5–8		Feldspar residues	Magnetite, apatite, zircon, rutile, sillimanite, weathered feldspar.	Biotite, epidote, chlorite, rutile, zircon, blue magnetite, sillimanite, tourmaline.	Quartz and zircons well rounded. Many secondary quartz grains other than crystals inclosing iron oxide.
Elkton	3	3			Rutile, tourmaline, chlorite, microcline, zircon, magnetite.	Muscovite, orthoclase, microcline, hornblende, rutile, epidote.	Angular and rounded, 1:1 admixture of grains. Less secondary quartz grains than primary.

SOIL FROM ICE-LAID MATERIAL.

Light-colored Timbered soils: Volusia	10-12	8-10	Microcline, orthoclase, very much altered and fresh.	Feldspar residues	Garnet, zircon, chlorite, biotite, hornblende, tourmaline, epidote, albite.	Chlorite, biotite, hornblende, epidote, muscovite, tourmaline.	Grains well rounded. Many secondary quartz grains. Orthoclase altered to epidote, also fresh orthoclase. Silt shows extensive chemical alteration.
Miami	10	10-15	Hornblende, garnet, microcline.		Orthoclase, zircon, epidote, plagioclase, oligoclase, apatite, garnet.	Tourmaline, hornblende, epidote, chlorite, orthoclase, microcline, zircon.	Well rounded. Most quartz grains show evidence of great wear.
Dark-colored Prairie soils: Carrington	15	20	Hornblende, epidote, garnet, magnetite, ilmenite, microcline, in some quantity, feldspars.	Hornblende, chlorite	Hornblende, chlorite, zircon, plagioclase, albite, oligoclase.	Epidote, biotite, calcite, rutile, muscovite, plagioclase, orthoclase.	Rounded to angular. Characterized by high-content feldspar and other minerals than quartz.

SOILS FROM WIND-LAID MATERIAL (LOESS).

Dark-colored Prairie soils: Marshall	12	15-20	Feldspars, including orthoclase, microcline, plagioclase, oligoclase, andesine.	Epidote, muscovite	Apatite, muscovite, hornblende, rutile, garnet, zircon, sillimanite.	Hornblende, biotite, chlorite, tourmaline, orthoclase, zircon, microcline, sillimanite.	Grains mostly angular, some fairly well rounded. Contains few quartz crystals. Orthoclase much altered, also fresh orthoclase.
Light-colored Timbered soils: Memphis	15	15	Feldspars, orthoclase, altered; microcline.		Biotite, albite, oligoclase, zircon, fluorite, rutile, tourmaline, apatite, hornblende.	Biotite, hornblende, epidote, muscovite, orthoclase, microcline, epidote, sillimanite, rutile, zircon.	Grains mostly well rounded, few angular; orthoclase in general highly altered.
White Prairie soils: Marion	10-12	12	Microcline, hornblende, orthoclase.	Orthoclase, hornblende.	Fluorite, zircon, garnet, tourmaline, plagioclase, oligoclase, epidote.	Tourmaline, microcline, epidote, titanite, chlorite.	Admixture of angular and well-rounded grains. Admixture of fresh and weathered orthoclase. Some minerals highly altered, others entirely fresh.

A very interesting case of the influence of topography upon the character of the soil is presented in the Cecil and Porters series. These two series are derived from the same kind of rocks and have very much the same minerals present, although the percentage of other minerals than quartz is about three times as great in the latter as in the former. The Porter series has a mountainous topography, and erosion has permitted only a thin mantle of soil to accumulate. The minerals show very slight alteration, indicating that they have not been long subjected to weathering. The Cecil series, on the other hand, occurs in the Piedmont Plateau, where the surface is not so broken, giving rise to less rapid erosion and more advanced decomposition.

Probably no more striking contrast between soils formed from the same group of rocks can be found than that exhibited by the Penn and Dekalb soils, representing the timbered humid region, and the Morton and Summit series of the black prairie region. The former two are very silicious, the average percentage of quartz in the sand and silt approximating 85 to 90 per cent, while in the last two it is sometimes less than 50 per cent. The feldspars, which, if present at all in the two humid series, are very much altered, occur in abundance in the prairie soils. In the latter, however, especially the Morton, there is a mingling of fresh and altered feldspar, indicating an admixture of materials. Apatite is also present in the latter, although absent from the former. Calcite is reported as abundant in the Morton series, something of unusual occurrence, the black glacial soils of the Carrington series being the only other series in which this mineral was found, except as inclusions in quartz crystals.

The reason for such marked contrast in these soils formed from the same group of rocks has already been discussed (see pp. 13 to 23), but may be briefly stated as being due not only to differences in the amount of leaching which has taken place, but also to differences in the history of the material composing them.

The limestone soils show hardly as great a contrast as one might expect, where so decided a difference in productiveness exists, as that between the Hagerstown and Clarksville. The percentage of other mineral than quartz is not very high, although nearly three times as great in the former as in the latter. Since these soils are composed almost entirely of fine silt and clay, there is reason to suppose that the minerals present in the limestones are there in very small particles.

The Hagerstown shows a rather unusual amount of feldspar, since limestones are considered to be free from feldspar, although it has been reported in exceptional cases; but in the Decatur, which is almost as productive as the Hagerstown, no feldspar at all is found. The only other series in which this is the case is the Louisa. The presence of the feldspar in the limestone soils is the result of admixture of material from other rocks. Secondary quartz crystals, often containing inclusions of calcite indicative of other origin, are abundant and characteristic in all the series. With the exception of fluorite none of the less common minerals appear in any of the limestone soils.

Four of the series analyzed represents soils derived from unconsolidated water-laid deposits. All of these are from the Atlantic Coastal Plain. With the exception of the Sassafras these series all show a high percentage of quartz, the sands ranging from 95 to 99 per cent or more of this mineral.

The Sassafras series is confined to the northern Coastal Plain, and the reasons for its less siliceous nature have been already discussed (see p. 74). It represents an admixture of rock material from many sources. The angular shape of the grains, as compared with the well-rounded forms of the Norfolk, show that the material composing it has not been subjected to as great a degree of wearing as the latter series.

The Sassafras and Elkton series furnish an excellent example of the change which may be brought about in soils from identically the same material through the processes of weathering (see p. 73). These two series are intimately associated, but the intermittent wet and dry conditions, which have existed where the latter occurs, has caused the disappearance of three-fourths of the minerals other than quartz that must have been present in the material originally. A comparison of the minerals present in the two series shows that biotite, apatite, hypersthene, plagioclase, and staurolite—a mineral peculiar to metamorphic clay slates and schists—are lacking in the Elkton, while magnetite is the only mineral present in this series which is not found in the Sassafras. A chemical analysis to see whether the percentage of silica in the entire soil mass has increased, with a corresponding decrease in the iron, phosphorus, etc., would be of much interest and might throw light upon the chemical changes which have taken place and possibly give an indication at least of the cause of the decidedly lower productiveness of the white Elkton soils. Such study, however, could not be made at this time.

The soils formed from glacial material are characterized by a relatively large percentage of other minerals than quartz, especially in the sands. This is undoubtedly due in the main to the grinding up of the rocks through the mechanical action of ice. Of the three series analyzed the Volusia and the Miami represent the Light-colored Timbered soils and the Carrington the Dark-colored Prairie soils. It should be noted that the last is characterized by a high content of feldspar and almost 50 per cent more of other minerals than quartz than is found in the humid series. The grains are less rounded, and calcite is also present. There is hardly as great a contrast between the Volusia and Miami soils as one would have expected, since the former consist largely of shale material while the latter are composed principally of ground-up limestones and crystalline rocks. This may be due, in part at least, to the inclusion of sandy soils in the composite sample of the Miami series, which was not done in the Volusia series.

Three types of loessial soil were selected for analysis—Marshall, Memphis, and Marion. The first is a Dark-colored Prairie soil, found in the northern Mississippi Valley, the second a Light-colored Timbered soil, occurring in the southern part of this valley, while the last is a white Prairie soil, confined almost entirely to southern Illinois. They represent types of decided difference in productiveness—the Marshall being one of the richest and the Marion one of the poorest soils in the country. The Memphis holds an intermediate position, though more like the latter than the former. They are all silt loams, and therefore quite comparable from a textural standpoint, which is not true of most of the series here included.

As about 75 per cent of the soil mass consists of silt, this grade should be given most weight in comparing these soils. The Marshall shows the largest and the Marion the smallest percentage of other mineral than quartz, although the difference is not very great. The feldspars are rather more abundant and of greater variety in the Marshall, especially in the sand. Andesine, muscovite and biotite micas, apatite, and sillimanite appear in the Marshall and not in the Marion, while the opposite is true of titanite and fluorite. It is very interesting to note that the Marion soil, which is low in phosphorus, does not contain any apatite, a mineral consisting of calcium phosphate.

A very interesting fact is brought out in the remarks relative to the shape of the grains and the weathering of the orthoclase in these soils. In the Marshall the grains are mostly angular, with some fairly well rounded, and there is an admixture of fresh and much altered orthoclase, while in the Memphis the grains are mostly well rounded, with a few angular, and the orthoclase is generally highly altered. The latter represents loessial material which was transported much farther southward and has therefore been subjected to more abrasion and decomposition. The Marion seems to represent an admixture of the two classes of material.

In order to show more clearly just what minerals are present in each series and whether they are abundant or in small quantity, the following table has been arranged:

Minerals present in important soil series.

Name of minerals.	Number in which found.	Fresno.	Yakima.	San Joaquin.	Cecil.	Porters.	Chester.	Louisa.	Iredell	Penn.	Dekalb.	Morton.	Summit.	Hagerstown.	Clarksville.	Decatur.	Elkton.	Sassafras.	Norfolk.	Greenville.	Volusia.	Miami.	Carrington.	Marshall.	Memphis.	Marion.
Quartz	25	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hornblende	23	A	A	A	S	A	A	S	A		S	A	A	S	S	S	S	A	S		S	A	A	S	S	A
Orthoclase	20	A	A	A	A	A			S	A	A	A	A	A			S	S	S		A	S	S	A	A	A
Microcline	20			S	A	A	S		S	S	S	S	A	A	S		S	S	S		A	A	A	A	A	A
Epidote	24	S	S	A	S	S	S	A	A	A	S	A	A	S	S		S	S	S	S	S	S	A	A	S	S
Biotite	21	A	A	A	A	A	A	S	A	S	S	S	S		S	S		A	S	S	S		S	S	S	
Muscovite	20	S	A	S	A	A	A	A		S	S	S	S	S	S	S	S	S			S		S	A	S	
Zircon	22	S		S	A	S		S		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chlorite	20			S	A	S	S		S	S	S	S	S	S	S		S	S	S	S	S	S	A	S		S
Tourmaline	21	S		S	S		S	S		S	A	S	S	S	S	S	S	S	S	S	S	S		S	S	S
Rutile	17			S		S	S	S			S		S	S	S	S	S	S	S	S			S	S	S	S
Plagioclase	13	A	A	A		S			S	S		S	A					S				S	S	A		S
Apatite	12	S	S						S			S	S					S	S	S		S		S	S	S
Garnet	10				S	S	S						S	S						S	S	A	A	S		
Sillimanite	10				A		S	A		S			S						S	S				S	S	S
Oligoclase	7			A								S	A									S	S	A	S	
Andesine	6	A	A	A	S				S															A		
Albite	5	A		A																	S		S		S	
Pyroxene	6	S	A			S			A	S			S													
Magnetite	6						S		S	S							S			S			A			
Labradorite	3		A						S				A													
Titanite	2			S																						S
Fluorite	4												S	S											S	S
Augite	2		A						A																	
Ilmenite	2								S														A			
Calcite	2											A											S			
Hypersthene	2		S															S								
Sericite	1							A																		
Phlogopite	1		S																							
Hematite	1									A																
Serpentine	1		S																							
Actinolite	1						S																			
Iddingsite	1		S																							
Staurolite	1																	S								
No. of minerals.	....	13	16	16	13	13	13	10	15	14	11	14	19	12	10	7	11	15	12	11	12	12	17	17	15	14

A=Abundant.

S=Accessory or less abundant.

The total number of minerals reported from all the series is only 34[1]—a smaller number than one might expect when the many different species which have been identified by mineralogists are considered. The number present in any one series varies from 7 to 19, the average being a fraction more than 13. Of the 34 minerals present only 1—quartz—is reported in all the series, although several others occur in nearly all of them and if it had been possible to determine the minerals in the fine as well as the coarser particles it is very probable that not only other minerals besides quartz would have been found in all the series, but also a greater number. One-fourth of the 34 appear in only 1 series, while only 12 are found in as many as one-half. Taking the 12 most common minerals it will be seen that only 4 series have them all present; 4 have 1 of the 12 missing; 11 have 2 missing; 2 have 3 missing; 2 have 4 missing, and 2 as many as 5 missing. It would thus seem that there is considerable variation in the mineralogical composition of the different series, even when only the most common minerals are considered, and that this variation becomes greater when those of less frequent occurrence are included. Soils usually have a greater variety of minerals than rocks, since they are often the result of the degeneration and transportation of many different rocks.

As regards the relation between the variety or number of minerals present and the productiveness of the soils, no very definite statements can be made or conclusions drawn. However, if the different series be arranged in the order of their productiveness it will be found that only four in the most productive half fall below the average for all the series, while in the least productive half 10, or all except three—two of which are loessial soils—are less than this figure. This would indicate that soils having a variety of minerals are on the average likely to be more productive than those having a less varied mineralogical composition.

In the Coastal Plain the Sassafras has a greater variety of minerals than either the Norfolk or the Elkton and is also more productive, but the Greenville, which is more fertile than the Norfolk, has fewer minerals. In the Piedmont Plateau the Iredell has a larger percentage than either the Chester or the Cecil, although less productive, but the Louisa has fewer than either and is decidedly less desirable. In the case of the sandstone and shale soils, as well as those of glacial and loessial origin, the more productive have in nearly every case a larger number of minerals present. The limestone soils are all rather poor in minerals, the Decatur, although an excellent soil, shows less than any other series, including the Clarksville. The

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[1] Some of the minerals included are really varieties of other minerals; thus, labradorite, andesine, oligoclase, and albite are all plagioclase feldspars and when not identifiable were so classed. Other examples also occur particularly among the iron minerals.

Hagerstown, however, has a higher percentage than the Clarksville and is much more productive.

Of the minerals found quartz is, of course, by far the most abundant. It is the only one of which any quantitative determination was attempted, except to state whether they were abundant or not. According to the determination the percentage in the different series varies from less than 50 per cent to more than 95 per cent, the average being about 83 per cent. Quartz constitutes about 40 per cent less of the silt than of the sand, indicating that a still smaller percentage would be found in the clay, and this is undoubtedly true. In general it may be stated that the amount of quartz is highest in soils derived from acidic rocks and in those where the material has undergone most attrition and decomposition; geographically the soils in the southeastern part of the United States.

While there are some exceptions it may be stated that, in general, the soils having the lowest percentage of quartz are the most productive. Much depends, of course, upon the nature of the other minerals present, but it is nearly always true when comparing soils derived from the same general group of rocks. It is probably least often the case in soils formed from igneous and metamorphic rocks, especially the former. In the soils from crystalline rocks the lowest percentage of quartz occurs in the Iredell series, although these soils are not as desirable as those of either the Chester or Cecil. The last two are decidedly more productive than the Louisa, which is more silicious. In the case of soils derived from sandstone and shales, from limestones, from water-laid, ice-laid, and wind-laid material, an arrangement under each division, according to the percentage of quartz, will correspond without a single exception to their productiveness. This is very strong evidence that there is an inverse relation between the amount of quartz and the productiveness of the soil when the comparison is made between soils derived from material formed by the same general agencies or processes. It would seem, therefore, that a determination of the percentage of quartz in all samples, which are analyzed mechanically and published in the soil survey reports, would be of considerable value.

Next to quartz the most common mineral is apparently epidote, although both hornblende and the two potash feldspars—orthoclase and microcline—may be considered as more abundant, since they occur as such in a larger number of series. Epidote is found as abundant in both good and poor soils and no apparent relation exists between its presence and the fertility of the soil.

Next to epidote, hornblende appears to be the most common mineral, although the potash feldspars both occur as abundant in a larger number of series. It is absent from only two, both of which represent decidedly red soils. Out of 12 series in which it is abundant 8 are above the average in productiveness, while 4 are below; in the 11 series in which it is least abundant 3 are above and 8 below. This would seem to indicate that the chances for a soil being productive are greater when this mineral is abundant. The two soils, however, from which it is absent are of at least average productiveness.

Taken as a whole the feldspars are, next to quartz, the most abundant mineral in the series examined, orthoclase and microcline being the most common varieties. There is apparently seldom any relation between the presence or abundance of these two potash feldspars and the productiveness of the soil. It should be noted, however, that the Hagerstown, in which they are abundant, is much more productive than the Clarksville. Of the 16 series in which the plagioclase feldspars occur, 10 are above the average in productiveness and 6 below; in the 9 series in which none appear 2 are above and 7 below, while every series in which any of them are abundant is of very high productiveness; all of which seems to indicate a direct relation between their presence and the fertility of the soil. It is interesting to note that every series in which the plagioclases do not appear are situated in the timbered humid regions of the eastern or southeastern United States, where the soils have been subjected to the greatest amount of leaching and attrition.

The micas—biotite and muscovite—chlorite, zircon, tourmaline, and rutile, are all common minerals, but with the exception of the micas are seldom abundant. The last three are all rather hard minerals, which resist wearing and weathering, and this doubtless accounts in part at least for their wide distribution.

Apatite is of much more importance than some of the minerals already mentioned, because it is the principal mineral carrying the agriculturally important element, phosphorus, in which some think our soils are most likely to be deficient. It is reported in 11 series, in none of which is it abundant. Of the 11, 7 are above the average in productiveness and 4 below. Taking the 14 series in which it is absent, 5 are above and 9 below the average. Its absence in nearly all of the series which are of very low agricultural value, taken in connection with the above facts, is rather significant.

An interesting and suggestive point in regard to the presence or absence of this mineral in "crawfishy" or "mascerated" soils should be brought out in this connection. Two such series—the Elkton and the Marion—are fortunately included. The former is derived from identically the same material as the Sassafras, but while apatite is present in the latter it is absent from the former. Likewise this mineral is found in two of the loess soils—Marshall and Memphis—but not in the Marion. It appears that the apatite has been attacked under stagnant water conditions, the phosphorus probably leached out or locked up in inert iron concretions which are characteristic of both soils.

One of the most peculiar things about the mineralogical analysis of the various soils is the almost total absence of the iron minerals—magnetite and hematite—which are so commonly found in rocks. This can probably be explained by the fact that all the soils examined were surface soils and that these minerals are easily attacked when organic matter is present.

The presence of magnetite may depend on slight differences in chemical composition, since some magnetites are found bright and unaltered and others have a thick coating of iron oxide, thus indicating differences in ability to resist chemical decomposition. These two types sometimes occur in the same soil.

While it has not been possible to draw as definite conclusions from these mineralogical analyses as one could wish, it is believed that enough data have been presented to show the value of such studies as another possible way of throwing light upon the complex problem of soil fertility and the changes which may be brought about by various processes. It should be borne in mind that the samples included only surface soils and that an analysis of the subsoils might give additional suggestions of value. It would certainly be interesting to know whether any marked differences exist between the surface soils and the underlying subsoils. As some of the surface soils, especially in the southeastern United States, are decidedly more sandy than the subsoils, one would naturally expect them to show a larger percentage of quartz. It is probable also that the larger percentage of organic matter in the surface soils would cause more leaching to take place and that the subsoils would not only show a smaller percentage of quartz but also a greater variety of minerals.

The samples analyzed were, as already stated, a composite of 10 samples taken in widely separated localities. They were selected to represent the series, which may include soils varying in texture from sand to clay, rather than the type. It would probably have been much better to have confined the samples to the same type. In fact, it would be well to have a number of analyses of the same type to see if there is much variation from place to place. It is hoped that further studies can be undertaken in order to determine more definitely the meaning and value of this line of soil investigation.

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MILTON WHITNEY, Chief.

STUDIES IN SOIL CATALYSIS.

BY

M. X. SULLIVAN AND F. R. REID,
Scientists in Soil Fertility Investigations.

WASHINGTON:
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1912.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., February 19, 1912.

Sir: I have the honor to transmit herewith the manuscript of a scientific paper entitled "Studies in Soil Catalysis," by Dr. M. X. Sullivan and Mr. F. R. Reid, of this bureau. This article forms an important contribution on some little-understood factors in soil fertility. The mild but effective oxidation shown to exist in soils has a very appreciable effect in aiding the decomposition of organic matter in the soil. Catalysis is a factor of importance which is closely associated with soil oxidation. The importance of the organic constituents of the soil makes these results especially interesting, and the material throws additional light upon the question of soil fertility. I have, therefore, the honor to recommend that this article be published as Bulletin No. 86 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The present paper is one of a series reporting upon the biochemical factors in soils. The causes of fertility and infertility of our agricultural lands are complex, not simple as some would have us believe, and it is only by a study of the chemical, physical, and biological activities going on in the soil that we can get a thorough insight into the problems of soil fertility. The purely chemical and physical sides have been studied quite extensively in the past; the biological side, however, but little. Whatever adds to our biochemical knowledge of soils advances and broadens our understanding of the complex problem of soil fertility. Accordingly, this laboratory has taken up a series of studies on biochemical factors in soils. Much valuable and definite information concerning the presence and properties of certain constituents of soils, produced by biochemical agencies, has already been obtained. Some of these have been shown to be harmful to plants and others decidedly beneficial. Some thirty compounds have thus far been definitely isolated and identified and through them a fairly comprehensive view of the biochemical changes which take place in soils obtained. The biochemical processes, however, by which changes are brought about are, on account of the very nature of the case, less definite and less tangible and require much further study before they can be thoroughly understood. I refer to the action of bacteria, of molds, and other life within the soil in producing chemical changes, of the activity of enzymes, and of such processes as deamidization, oxidation, reduction, and catalysis. The biochemical factors of oxidation and reduction in soils by plant roots and other powers have already received consideration in earlier bulletins and a study of the closely related subject of catalysis is given in the present paper.

Oxidation in soils is perhaps one of the most important processes in the soil and is well recognized in practical tillage. Besides the purely chemical oxidations there are the biological agencies which are perhaps the ones most persistent in soil oxidation. Among these are the oxidizing functions of bacteria, of molds, and of plant roots, and of the enyzmes produced by these agencies. Oxidation by plant roots is a factor which has considerable agricultural interest, especially from the viewpoint that such oxidation is able to change the organic matter in the medium in which the plant is growing and that processes promoting oxidation play a large part in the best methods of soil cultivation, tillage, and crop rotation. The oxidation of organic matter in the soil is of additional interest in that the investigations of this laboratory have shown that the cause of unproductivity in certain soils is due to the presence of harmful organic matter in the soil. The beneficial effect of oxidation in such soils can be inferred from the effects of tillage, involving subdrainage and cultivation, since these operations promote aeration of the soil with subsequent increase of roots and microorganisms and an increase in the measurable oxidative property.

Valuable and necessary as are these oxidative functions in the soil, to produce sanitary surroundings for the plant and to promote decomposition of organic débris so that valuable plant nutrients may again be started on their way to produce new foodstuffs for plant and animal, an excessive amount of oxidation is, on the other hand, undesirable and dangerous to the proper functioning of the soil. Whatever induces excessive oxidation in soil, plant or animal, is undoubtedly injurious. Excessive oxidation produces or accompanies diseases in both animals and plants. In plants, chlorophyll is destroyed and a group of plant diseases are accompanied by great oxidative power of the plant juices. Strong oxidizing agents are poisonous to plant life, whether they be organic or inorganic in character. Under normal conditions such excessive oxidation, resulting in the formation of peroxide material, is probably prevented or controlled by a catalytic property inherent in vegetable and animal tissues, and this same property of preventing excessive oxidation has been found to exist in normal soil. The present paper is a contribution to this subject and throws much light upon the nature of catalysis and its correlation with soil conditions and different soil types. The paper will show that this property of catalysis is especially prominent in strong, vital soils. These various factors of oxidation, reduction, catalysis, and others still to be reported on can doubtless be all correlated in a manner which will give us still greater and more complete insight into the biochemistry of soils.

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STUDIES IN SOIL CATALYSIS.

INTRODUCTION.

By soil catalysis is meant the power inherent in soils to decompose peroxides, especially hydrogen peroxide, with the liberation of oxygen as a measurable factor.

The soil, as is clearly recognized at the present day, is not merely a reservoir for the nutrients of plants, but is rather the seat of complex physical, chemical, and biological action which directly and indirectly influences fertility.

The various factors at work in soils have been extensively studied with the main stress, until recent years, upon the physical and chemical side. Within the last decade or two, however, much attention has been given to the biochemical side of soil and much valuable work has been done along this line, especially in the field of soil bacteriology. The work of soil bacteriology, however, has been limited for the most part to the study of the nitrogen problem, to denitrification, nonsymbiotic and symbiotic fixation of nitrogen, and to ammonification. On the other hand, biochemical factors in soil, such as the nature of the organic matter of soils and the change produced in soil constituents by microorganisms, the synthesis of organic compounds in soils, the presence of enzymes, the effect of plant growth on the soil and soil constituents, the physiological effect of organic soil constituents on plants, the action of fertilizers, and the oxidizing, reducing, and catalyzing powers of the soil, have received less consideration until recently in this and other laboratories. Using the methods employed in plant and animal physiology, the oxidizing power of the soil per se and in conjunction with plant growth and fertilizers was shown to be correlated more or less with the productivity of the soil in that, as a rule, soils with good oxidizing power were the productive soils, while most soils known to be of poor productivity had poor oxidizing power and that factors favoring fertility favored oxidation.[1]

Associated with the oxidizing power of plant and animal tissue is the power to decompose hydrogen peroxide with the evolution of oxygen. This property of the tissues to decompose hydrogen peroxide has been generally attributed to the enzyme catalase, and the process is known as catalysis.

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[1] Bulletin 73, Bureau of Soils, U. S. Department of Agriculture (1910).

New knowledge of every factor in soils is a step in advance toward a better understanding of soil fertility. Thus the study of the oxidizing power of the soil was found a fruitful field for research which threw some additional light on the problems of soil fertility. Considerable attention therefore has been given to the catalytic power of the soil in its relation to soil varieties and types, to plant growth, and to fertilizer action. These results are given in the present paper.

A catalyst, according to Ostwald,[1] is a body which alters the rate of change in a reaction. The change may be either in the direction of acceleration or retardation, and the reaction may be one that by itself proceeds rapidly or so slowly that it requires special proof to show that it is taking place at all. It is especially to the acceleration of reaction that the term catalysis is usually applied. Without going further into the discussion of the characteristics of catalytic reactions, it may be said that by the catalytic decomposition of hydrogen peroxide is meant the rapid breaking up of the hydrogen peroxide into water and oxygen in the presence of another substance. The acceleration of the decomposition of hydrogen peroxide by certain substances has long been known.

Thénard [2] early studied the catalytic decomposition of hydrogen peroxide and concluded that most bodies affect the peroxide. Some, like the acids, phosphoric, hydrofluoric, sulphuric, hydrochloric, arsenic, and oxalic, tend to increase its stability, while the metals, metallic sulphides, oxides, and carbon tend to decompose it. He noted later [3] the analogous action of the noble metals, silver and platinum, and animal tissue on hydrogen peroxide and thought it probable that its decomposition was due to the same force in each case. Berzelius [4] compared the contact action of platinum, silver, etc., in decomposing hydrogen peroxide with the action of the ferments. Schönbein [5] greatly extended these observations and pointed out that many organic substances decomposed hydrogen peroxide and found that this catalytic activity was widespread in plant and animal tissues. He found that certain poisons, especially hydrocyanic acid, exercised a similar retarding action on the decomposing power of metals and of ferments. He believed further that all ferments were able to decompose hydrogen peroxide; a belief that persisted until 1888, when Bergengrün [6] found that the fibrin ferment did not decompose the peroxide. Later Jacobson[1] showed that there is no parallel between the catalytic action of the enzymes, emulsin, trypsin, and diastase on hydrogen peroxide and their other activities and proved that enzymes might lose the catalytic power without losing their specific activities.

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[1] Zeit. Electrochem. 7, 995 (1900–01).

[2] Ann. chim. et phys., 9, 314, 441 (1818).

[3] Ann. chim. et phys., 11, 85 (1819).

[4] Berzelius, Jahresber., 78, 237 (1836).

[5] Jour. prakt. Chem., 89, 323 (1863).

[6] Ueber die Wechselwirkung zwischen Wasserstoffsuperoxyd und verschiedenen Protoplasma-Formen. Dorpat 1888.

Spitzer[2] believed that the power to decompose hydrogen peroxide is a measure of the oxidizing power of various animal tissues. Lépinois,[3] contrary to the views of Spitzer, showed that for the various tissues there does not always exist a parallelism between the quantity of oxygen evolved from hydrogen peroxide and the intensity of oxidation of guaiacum and guaiacol.

Up to 1901 the power to decompose hydrogen peroxide was considered a more or less general property of enzymes. In 1901, however, Loew,[4] while working on the tobacco plant, found that this power of tissues is due to a special enzyme which he called catalase. He found catalase so widespread in animal and plant tissue that he decided there did not exist a group of organisms or any organ or cell which did not contain some catalase. Since Loew's discovery of the enzyme catalase the work on catalase in plant and animal tissue has been very extensive. This work has been recently summarized by Battelli and Stern.[5]

As to the function of the catalase little can be said. According to Loew,[6] Herlitzka,[7] Battelli and Stern,[8] and Shaffer,[9] the catalase of plant and animal tissue protects the tissue against excessive oxidation. Though the catalytic power is usually associated with the oxidizing power, the relation between oxidation and catalysis is by no means clear nor is the function of catalase fully understood. Indeed the only function of catalase that is known with certainty is its power to decompose hydrogen peroxide in a manner analogous to that of colloidal platinum.

The action of colloidal solutions of metals has been studied by Bredig and his coworkers,[10] by Kastle and Loevenhart,[11] Liebermann,[12] and Senter.[13]

Between the action of catalase and the different metallic catalyzers on hydrogen peroxide there is considerable resemblance. In fact

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[1] Zeit. physiol. Chem., **16**, 340 (1892).

[2] Arch. ges. Physiol., **67**, 615 (1897).

[3] Compt. rend. Soc. Biol., **51**, 401 (1899).

[4] Report 68, U. S. Department of Agriculture (1901).

[5] Ergebnisse der Physiol., **10**, 531 (1910).

[6] Loc. cit.

[7] Rend. Sci. Fis. Mat. et Nat. Real Acad. Lincei, **16**, ser 5, part 2, 473 (1907).

[8] Compt. Rend., **141**, 1044 (1905).

[9] Am. Jour. Physiol., **14**, 299 (1905).

[10] Zeit. phys. Chem., **31**, 258 (1899): **37**, 1, 323 (1901).

[11] Am. Chem. Jour., **29**, 397, 563 (1903); Am. Jour. Physiol., **13**, 171 (1905).

[12] Arch. ges. Physiol., **104**, 119, 155 (1904).

[13] Zeit. phys. Chem., **44**, 257 (1903); **51**, 673 (1905).

Bredig considered the analogy so close that he spoke of the inorganic catalyzers such as colloidal platinum as "inorganic ferments." In other words, he considered the colloidal solutions of the metals as inorganic types of the organic ferments. Loevenhart and Kastle's work, however, showed that the analogy is probably a coincidence, since many substances act differently with the two orders of catalyzers, in that they may inhibit the one and accelerate the other. Liebermann[1] also thinks that the mechanism of the decomposition of hydrogen peroxide by colloidal platinum and by catalases of animal or vegetable origin is essentially different. According to Liebermann, active oxygen is formed in the decomposition of hydrogen peroxide by platinum, while in the case of catalase of animal and plant origin, no active oxygen is formed. The most important difference between catalase and inorganic catalyzers is, as pointed out by Loew,[2] that the action of catalase is specific while the colloidal metals not only decompose hydrogen peroxide, but also oxidize guaiac and cause reduction. Whether the inorganic catalyzers and catalase act in exactly the same way or merely in analogous ways is still an unsettled question. In both cases, the mode of action is still a matter of theory. However, the fact that a hydrogen peroxide decomposing force is present in soil is rather interesting and the study of this power should offer a fruitful field of research, either by itself or in association with other soil factors.

DECOMPOSITION OF HYDROGEN PEROXIDE BY SOILS.

As pointed out by König, Hasenbäumer, and Coppenrath,[3] soil has the power to liberate oxygen gas from hydrogen peroxide. They believed that the decomposition of the peroxide was brought about mostly by the enzyme catalase which was associated with the bacteria of the soil and to a smaller degree to inorganic colloids which behave somewhat as platinum black. Later[4] these investigators studied the hydrogen peroxide decomposing power of soil in greater detail and ascribed it as before to the enzyme existing in soils and to the colloidal action of the oxides of manganese and iron, Mn_3O_4 and Fe_2O_3. In their earlier studies they found that different soils decompose the peroxide in different degrees. Calcareous soils had the greatest activity, then clay, loam, sandy loam, and sandy soil. In their latter work they found that the power is in almost direct relation to the humus content of soils. Clay soils, however, with small humus content and large manganese content develop the larger proportional amount of gas, so that it would seem from their work that the catalytic power of the soil is dependent on both the organic and the inorganic matter.

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[1] Ber. deutsch. chem. Ges., **37**, 1519 (1904).

[2] Loc. cit.

[3] Landw. Vers-Sta., **63**, 471 (1905-6).

[4] Landw. Vers-Sta., **66**, 401 (1907).

Later May and Gile made a detailed study of some Porto Rican[1] soils and concluded that the power of a soil to decompose hydrogen peroxide depends upon the catalase content, enhanced only in special cases by the colloidal action of the mineral constituents. This property they considered was a rough measure of the combined quantity of bacteria and organic matter present in the soil. The most accurate method of comparing different quantities of catalase they found to be the measurement of the rate of reaction or time required to evolve a certain volume of oxygen from a certain quantity and concentration of hydrogen peroxide.

In this laboratory, likewise, it was concluded (1) that the amount of oxygen evolved by a certain quantity of soil for a certain amount of peroxide signified little since a small amount of a catalytic agent, unless destroyed in the reaction, will decompose as much peroxide as a larger amount although at a slower rate; (2) that the best measurement of the catalytic power of soils is a measurement of the rate or the time required to evolve a certain volume of oxygen from a definite quantity and concentration of the peroxide; (3) that both the total volume of oxygen evolved and the rate of evolution should be considered in judging the relative catalytic power of soils.

The speed of the reaction between catalase and hydrogen peroxide as shown by May and Gile depends upon (1) the amount of catalase present; (2) the concentration of the peroxide used; (3) the amount of peroxide used; (4) the acidity or alkalinity of the solution in which the reaction takes place; (5) the temperature at which the reaction takes place; (6) the frequency with which the flask containing catalase and the peroxide is agitated.

METHOD OF TESTING THE CATALYTIC POWER OF SOILS.

Five grams of air-dried soil were placed in a large test tube having a capacity of 90 c. c. provided with a two-holed rubber stopper through which passed a small dropping funnel and a glass tube connecting with a gas-measuring tube. The peroxide used was a slightly acid rather stable solution containing approximately 3 per cent hydrogen peroxide by weight. Before using the peroxide it was made faintly alkaline to phenolphthalein by means of dilute sodium hydroxide. The neutralized peroxide, somewhat diluted, was dropped upon the soil by means of the funnel, and the oxygen was collected in the measuring tube. As a rule 10 c. c. of approximately 1½ per cent hydrogen peroxide solution was used in the experiments. The criterion for the catalytic power of the soils was the time required to evolve 50 c. c. of oxygen. In the experiment each tube was shaken once every minute for 15 seconds. The results are strictly comparable only in each experiment where the same neutralized peroxide was used and the temperature conditions were the same. No corrections were made in the volume of oxygen for variations in temperature and barometric pressure since the method was considered useful only in determining fairly wide and distinct difference in catalytic power. In the reaction between the hydrogen peroxide and soil, heat is generated. The increase in temperature varies from 2 degrees in slow catalyzers to 5½ degrees in rapid catalyzers. The apparatus employed is shown in Plates I and II.

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[1] Circular 9. Porto Rico Agr. Expt. Sta. (1909).

CATALYTIC POWER OF SOILS.

Since in certain experiments it was found that the acid of the peroxide lessened the catalytic power of the soils a high-grade neutralized peroxide was used as described in the method, given already. The catalytic power of a number of soils is given in Table I.

TABLE I.—*The catalytic power of soils.*

Soils.	Quantity of oxygen evolved in—				Time to evolve 50 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	
	C. c.	*C. c*	*C. c.*	*C. c.*	*Minutes.*
Hagerstown loam plus manure	49.7	59	61	61	7.2
Hagerstown loam plus complete fertilizer	52	61	62	62	6
Hagerstown loam plus lime and manure	57	58	58	58	3.6
Hagerstown loam plus lime	63	64	64	64	3
Hagerstown loam	53	59	61	61	5.3
Clarksville silt loam, Tennessee	50	55	56	56	7
Clarksville silt loam, Kentucky	61	61	61	61	1.9
Sharkey clay	64	68	68	68	3
Volusia silt loam	30	44	57	62	21
Dutchess silt loam	37	52	61	62	14
Woodland soil, Reading, Conn	56	61	61	61	5.2
Orangeburg loam	62	64	64	64	1.3
Arlington clay loam	15	22	28	33	....

As may be seen from the table, the various soils differ considerably in catalytic power. Soils which gave the greater decomposition of the hydrogen peroxide were soils which were known to be of good productivity, while the poor soils had, as a rule, poorer catalytic power. The catalytic power and productivity, however, do not necessarily agree, since there are soils of slight catalytic power which give good crop growth. Crop production, as is well known, is dependent upon many factors, no one of which can be taken as an absolute criterion. The ability to decompose hydrogen peroxide, though not a necessity of the soil for the best productivity, seems to be symptomatic, however, of strong vital soils, in which various soil factors, as suitable organic matter, bacterial activity, oxidation power, etc., are prominent. The relation between the strong, vital soils and the poor soils seems to be comparable to that found by Winternitz and Meloy[1] between normal tissue and diseased tissue in that in general the normal tissue had the greater catalytic power.

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[1] Jour. Exp. Med., 10, 759 (1908).

RELATION BETWEEN THE OXIDIZING AND THE CATALYZING POWER OF SOILS.

In plants there seems to be a certain amount of association between the oxidizing and the catalyzing power. In soils it becomes of interest to see if the oxidizing power and the power to decompose hydrogen peroxide are correlated in any way. It was found that as a rule the soils with strong oxidizing power were the better catalyzers, while soils of poor oxidizing power were poor catalyzers. The relation between the two factors is not a direct one since the order of oxidation is not necessarily the order of catalysis as the following table shows:

Table II.—*Order of catalysis as compared with the order of oxidation.*

Soil.	Order of oxidation.	Order of catalysis.
Clarksville silt loam, Kentucky	1	1
Frankstown stony loam	2	3
Hagerstown loam plus manure	3	4
Wheeling gravelly loam subsoil	4	6
Wheeling gravelly loam soil	5	5
Clarksville silt loam, subsoil, Kentucky	6	2
Frankstown stony loam, subsoil	7	7

In the case of oxidation in the experiments already reported it was not possible to extract the oxidizing principle from the soil with water or glycerine. So in the case of catalysis no catalyzing principle could be extracted from the soils by water, glycerine, and dilute alkalies. Both the oxidizing principle and the catalyzing principle are probably present in the soil in not very great quantities and are absorbed by the soil to such an extent that it is not possible to extract them, or they are changed in the process of extraction.

The power of oxidizing easily oxidizable substances and the power to decompose hydrogen peroxide do not necessarily go hand in hand, since the addition of citric acid to certain soils increases the oxidative power while greatly decreasing the catalytic power. Again the oxidizing power may be lost while the catalyzing power is still present, though weakened. Thus the oxidizing power may be practically destroyed by using the soil several times in succession to oxidize aloin as brought out by the following experiments: Ten grams of soil were treated with 70 c. c. of a one-eighth per cent aloin solution. The mixture was then centrifuged and the supernatant oxidized aloin solution was poured off and the soil again treated with 70 c. c. of fresh aloin solution. After three oxidation tests in this way the soil had practically no power to oxidize the aloin. The same treatment was made with the soil and water only. The soils were then dried at the room temperature and 5 grams of each soil was tested for its catalytic power in relation to the soil untreated. The results are shown in Table III.

TABLE III.—*Effect of loss of oxidation and treatment with water on catalytic power of soil: (A) Catalytic power of soil deprived of oxidation power, (B) of soil treated with water as in the oxidation experiment, (C) of untreated soil.*

Soils.	Quantity of oxygen evolved in—					Time to evolve 40 c. c. of oxygen.	Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	145 minutes.			
Hagerstown loam plus manure:	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*Minutes.*	*Minutes.*	*Minutes.*
A	23	34	43	53	60	25	48.1	144
B	30	46	56	60	62	11.7	20	48.3
C	47	57	59	59	60	4.8	8.4	103
Hagerstown loam plus complete fertilizer:								
A	26	39	56	57	61	16.3	29.1	76
B	45	59	62	62	63	5.1	8.6	17.6
C	52	61	62	62	63	3.9	6.2	12.2
Hagerstown loam, lime, and manure:								
A	50	60	61	61	62	4.5	7	14
B	63	67	67.1	67.1	67.3	2.5	3.8	5.7
C	66	67.3	67.5	67.5	67.6	1.2	1.9	3.2
Hagerstown loam plus lime:								
A	57	66	66.7	66.7	67.2	3.1	4.8	9.6
B	55	65	75	75	75.7	3.3	5	9.8
C	67	68.3	68.6	68.6	68.8	1.7	2.7	4.6
Clarksville silt loam, Kentucky:								
A	61	66.3	66.3	66.3	....	2.7	4	6.4
B	65.5	65.7	65.7	65.7	....	1.1	1.6	2.8
C	65.5	66.5	66.5	66.4	....	1	1.3	2.2
Orangeburg loam:								
A	59	61	61.3	61.2	....	2.1	3.6	8.3
B	63	63	63.2	63.2	....	.8	1.2	2.5
C	62	62	62.4	62	....	.8	1.2	3

Treating the soil with water decreased the rate considerably in most cases, but by no means as much as treating with the same amount of aloin solution. The loss of the oxidizing power, while markedly decreasing the rate of catalysis, had little effect on the total amount of oxygen evolved from the hydrogen peroxide. There is some relationship between the forces bringing about the oxidation of easily oxidizing bodies and those decomposing hydrogen peroxide.

CATALYTIC POWER OF SUBSOILS.

In general, the subsoils are less productive than the surface soils. In studying the relation of oxidation to productivity it was found that the oxidation power of the subsoil, as a rule, was poor in comparison with that of the corresponding soil.[1] In a less marked degree than in the case of oxidation, the catalytic power of the subsoil is less, as a rule, than that of the soil, as may be seen in Table IV. These soils and subsoils were air-dried samples of soil, which had recently come from the fields.

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[1] Bul. 73, Bureau of Soils, U. S. Dept. Agr., 1910.

TABLE IV.—*Catalytic power of soils and subsoils.*

Soils.	Quantity of oxygen evolved in—			Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.		
Clarksville silt loam, Kentucky:	*C. c.*	*C. c.*	*C. c.*	*Minutes.*	*Minutes.*
Soil	64	65	65	1.75	2.6
Subsoil	62	62	62	1.75	3.2
Frankstown stony loam:					
Soil	65	65	66	2.2	3.3
Subsoil	13	19	26	....	....
Dekalb silt loam:					
Soil	59	63	64	4	7.5
Subsoil	9	14	18	....	....
Wheeling gravelly loam:					
Soil	40	56	61	11	21
Subsoil	34	51	60	13.6	30
Amarillo silt loam:					
Soil	56	62	63	5	10
Subsoil	47	57	60	8	30
Dunkirk clay:					
Soil	16	22	27	....	....
Subsoil	35	49	55	8.8	15.5
Clyde loam:					
Soil	23	37	51	28	....
Subsoil	7	9	12	....	....
Decatur clay loam:					
Soil	68	69	69	3.6	....
Subsoil	54	63	66	11.3	....
Norfolk sandy loam:					
Soil	17	22	28	....	....
Subsoil	12	15	17	....	....
Cecil clay:					
Soil	39	50	54	15	....
Subsoil	39	50	56	14.5	....

The catalytic power of the recently dried samples of subsoil was less than that of the surface soil in 8 out of 10 cases. It is most probable that many factors which make for soil fertility are more prominent in soils than in subsoils. The reaction between the catalytic power of the soil and subsoil was then extended to samples of soil which had been in an air-dried condition in Mason jars for a number of years.

TABLE V.—*Catalytic power of soils and subsoils (old samples).*

Soils.	Collected.	Quantity of oxygen evolved in—						Time to evolve 30 c. c. of oxygen.	Time to evolve 40 c. c. of oxygen.	Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
		7 minutes.	15 minutes.	30 minutes.	45 minutes.	60 minutes.	90 minutes.				
Dekalb silt loam:		*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*Min.*	*Min.*	*Min.*	*Min.*
Soil	1906	52	60	62	62	62	62	2.3	3.6	6	14
Subsoil		6	8	12	14	16	19	......	......	......	......
Fayetteville loam:											
Soil	1907	53	61	62	63	64	65	2.5	3.6	5.8	11.5
Subsoil		11	18	27	35	41	48	35.5	58.3	100	......
Norfolk loam:											
Soil	1907	47	61	68	68	69	69	3	5.2	8.5	13.7
Subsoil		3	5	7	8	10	13	......	......	......	......
Wheeling gravelly loam:											
Soil	1906	55	60	63	63	63	63	3.6	5.6	8.9	15.2
Subsoil		35	52	59	61	61	61	5.3	9.1	13.7	34.5
Susquehanna fine sandy loam:											
Soil	1906	20	32	43	49	55	59	14	24.5	46.2	94.5
Subsoil		......	......	......	1	2	4	......	......	......	......
Lufkin sand:											
Soil	1905	33	48	57	60	62	64	5.9	10.2	16.8	42.8
Subsoil		14	28	44	53	58	61	16.8	25.2	......	78

The table shows that the catalytic power persists more or less in the samples left in a dry condition in the laboratory for several years, and that in these old samples the catalytic power of the surface soils is greater than that of the subsoil. Since true enzymes, such as the amylolytic, proteolytic, and inverting enzymes, readily undergo decomposition, it seems rather unlikely that the catalytic power of the old samples of soils which had been for years in a dry condition in closed Mason jars is due to enzyme action. It may be said in passing, however, that Loew reported catalase in leaves of tobacco dried for many years, although other enzymotic activities were negative.

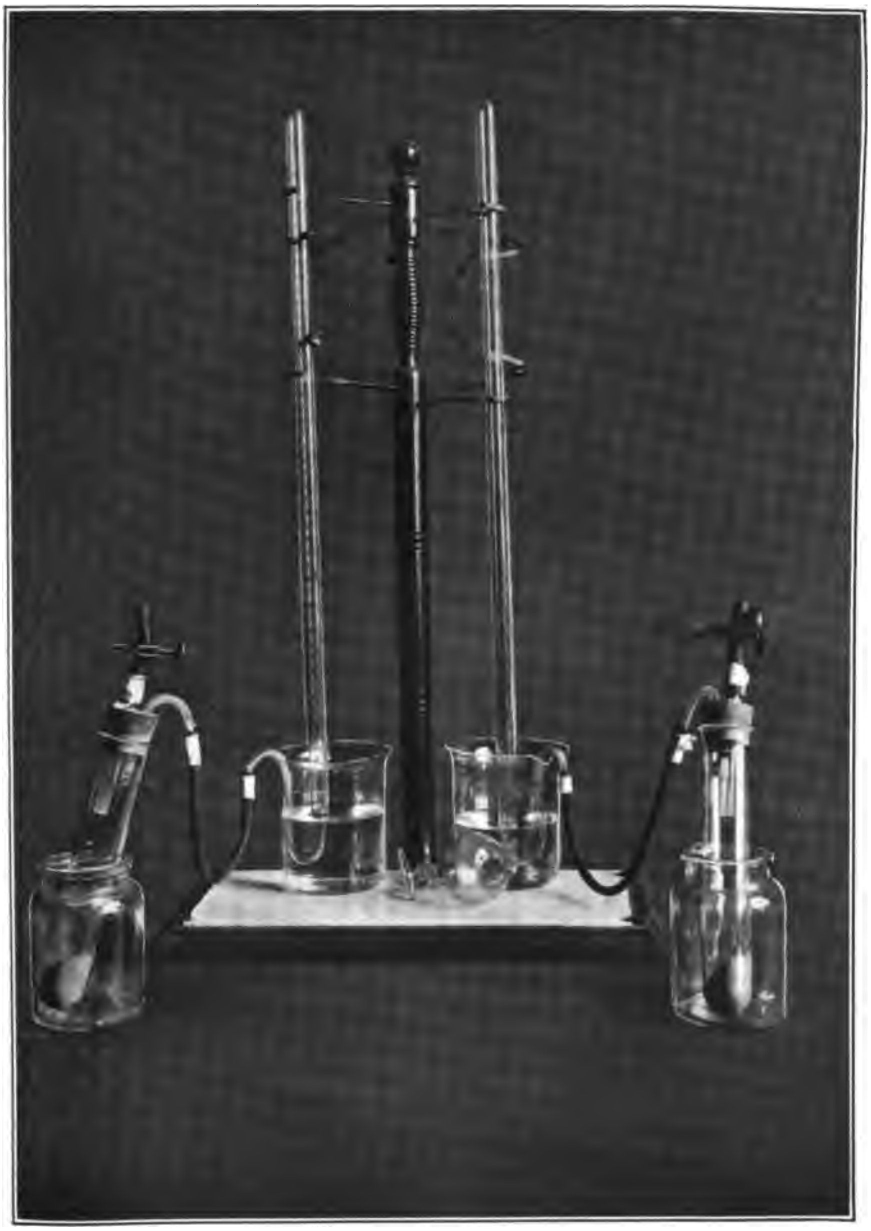
EFFECT OF FERTILIZERS AND PLANT GROWTH ON CATALYTIC POWER.

The air-dry samples of soils, Frankstown stony loam, Takoma Park soil, Amarillo silt loam, Westmoreland clay, Clarksville silt loam, and Dekalb silt loam, were treated with distilled water until the water content was 18 per cent of the air-dry soil. Then, on the basis of air-dried soil, $NaNO_3$, K_2SO_4, $CaH_4(PO_4)_2$, and mixtures of equal parts of these three salts were added to the soils in the ratio of 50 pounds of NH_3, K_2O, and P_2O_5 per acre; manure in the ratio of 25 tons to the acre; manure and lime in the ratio of 25 tons of manure and 2 tons of lime ($CaCO_3$) to the acre; lime ($CaCO_3$) 2 tons to the acre; ground cowpeas, well rotted, 5 tons to the acre. The soils were placed in pots, two pots to each treatment, and wheat, six plants to the pot, was grown for 18 days; then the green weight of the plants was taken, and on the following day the sifted samples were tested for the oxidative power and two days later for their catalytic power. The results are given in Table VI:

TABLE VI.—*Catalytic power of fertilized and planted soils.*

Soil.	Treatment.	Green weight of wheat.	Quantity of oxygen evolved in—				Time to evolve 40 c. c. of oxygen.	Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
			7 minutes.	15 minutes.	30 minutes.	60 minutes.			
		Grams.	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*Min.*	*Min.*	*Min.*
Frankstown stony loam.	N	3.060	55	58	58	....	2.5	4.5	....
	K	3.330	58	62	62	....	2	3.6	10.5
	P	2.870	55	57	57	....	2.5	4.4	....
	NKP	2.748	53	57	57	....	3	5.5	....
	NKP	(1)	....	....	....	....	....	....	....
	Manure	3.605	55	60	60	....	2	3.4	10.5
	Manure and lime	3.260	56	58	58	....	2	3.6	....
	Lime	2.960	58	61	61	....	1.9	3.2	9.25
	Cowpeas	3.432	58	60	60	....	1.9	3.3	14
	Check	2.790	57	60	60	....	2	3.3	10
	Check	(1)	57	61	61	....	2.25	4.6	12.6
Takoma lawn soil.	N	1.530	5	10	16	23	....	....	....
	K	1.690	5	9	13	14	....	....	....
	P	1.925	8	14	20	27	....	....	....
	NKP	2.106	6	11	17	24	....	....	....
	NKP	(1)	5	10	15	20	....	....	....
	Manure	2.545	8	13	21	26	....	....	....
	Manure and lime	4.115	12	20	27	36	....	....	....
	Lime	3.670	9	15	22	29	....	....	....
	Cowpeas	3.230	10	16	24	29	....	....	....
	Check	1.980	5	9	15	19	....	....	....
	Check	(1)	5	9	15	20	....	....	....

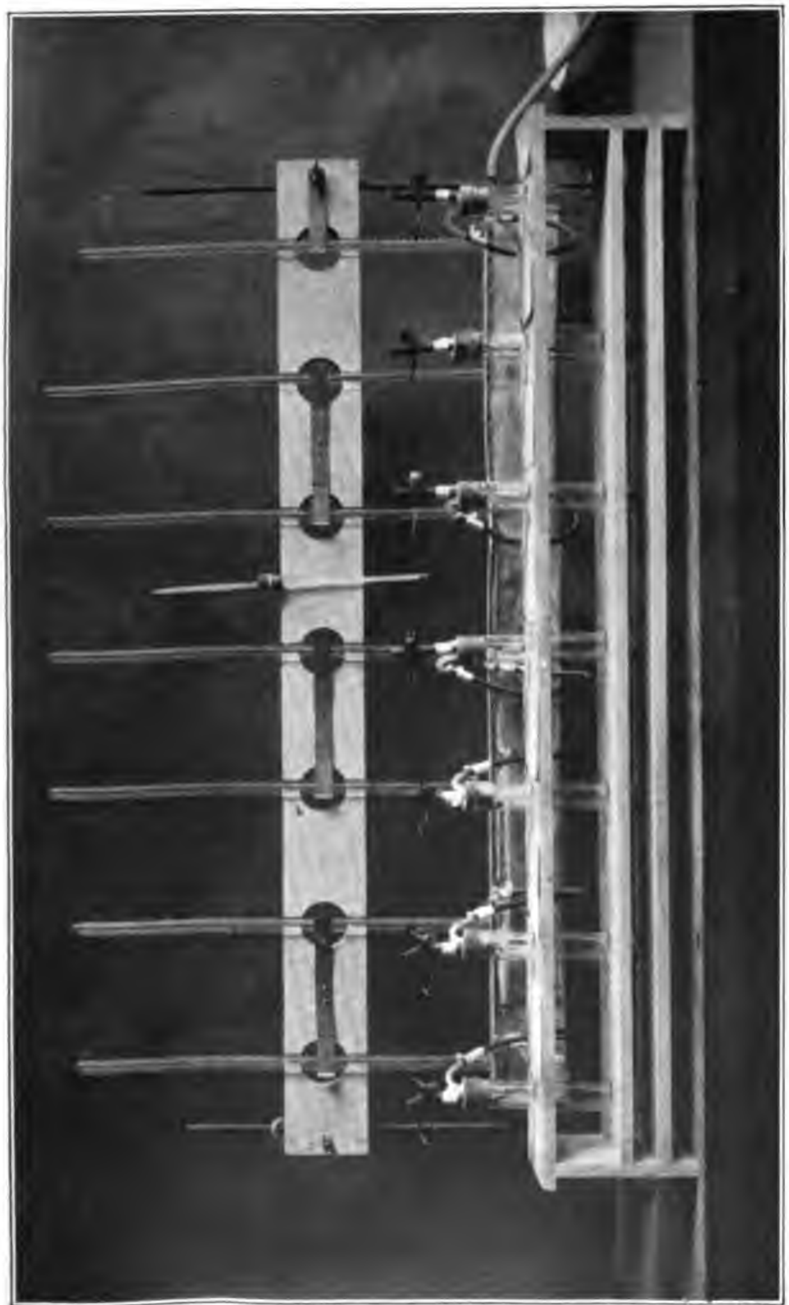
[1] Not planted.



APPARATUS FOR DETERMINING THE CATALYTIC POWER OF SOILS.

U of M

PLATE II.



IMPROVED FORM OF APPARATUS FOR DETERMINING THE CATALYTIC POWER OF SOILS.

TABLE VI.—*Catalytic power of fertilized and planted soils*—Continued.

Soil.	Treatment.	Green weight of wheat.	Quantity of oxygen evolved in—				Time to evolve 40 c. c. of oxygen.	Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
			7 minutes.	15 minutes.	30 minutes.	60 minutes.			
		Grams.	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*Min.*	*Min.*	*Min.*
Amarillo silt loam.	N	3.785	55	60	62	....	2.5	5	14
	K	3.615	53	59	61	....	3.6	5.8	20.5
	P	3.450	53	59	61	....	3.2	5.5	19.75
	NKP	3.670	52	56	59	....	3.3	6.25	18.5
	NKP	(1)	54	58	60	....	3.2	5.5	23.5
	Manure	3.450	53	58	62	....	3.3	6.1	19.2
	Manure and lime	3.455	54	59	62	....	3	5.25	17.4
	Lime	3.130	53	58	60	....	3.25	5.3	20.6
	Cowpeas	3.300	52	58	59	....	3.6	5.8	....
	Check	3.405	53	58	61	....	3.25	5.6	18.5
	Check	(1)	53	60	63	....	4.1	6	14.3
Westmoreland clay.	N	3.160	30	41	50	....	14.5	28.8	....
	K	3.290	27	39	50	....	15.8	29.3	....
	P	2.560	27	38	48	....	17	....	....
	NKP	2.060	26	37	46	....	18.75	....	....
	NKP	(1)	27	40	50	....	15.25	29.2	....
	Manure	3.035	30	40	51	....	15.3	27.5	....
	Manure and lime	3.610	32	43	56	....	12.2	21.3	....
	Lime	3.110	31	43	56	....	12.1	21	....
	Cowpeas	3.000	27	37	48	....	17.3	34	....
	Check	2.500	28	37	50	....	16.5	29.8	....
	Check	(1)	24	34	48	....	21.5	....	....
Clarksville silt loam, Kentucky.	N	3.300	59	61	....	....	1.6	2.8	9.25
	K	3.190	58	61	....	....	3.5	5	11
	P	3.112	61	61	....	....	1.6	2.6	5.80
	NKP	3.140	59	60	....	....	1.6	2.9	8.25
	NKP	....	....	....	....	....	....	....	....
	Manure	3.270	58	63	....	....	2.1	4.2	7.5
	Manure and lime	3.390	60	62	....	....	1.3	2.25	6
	Lime	2.940	59	61	....	....	1.6	2.6	11.8
	Cowpeas	3.020	55	59	....	....	2.8	5.5	....
	Check	2.955	56	57	....	....	1.75	4.25	....
	Check	(1)	....	....	....	....	....	....	....
Dekalb silt loam.	N	3.375	51	55	59	....	3.8	6.75	....
	K	3.500	52	57	62	....	3.6	6	19.5
	P	3.051	51	54	57	....	4	7	....
	NKP	3.450	50	54	56	....	4.2	7	....
	NKP	....	51	59	60	....	3.5	6.25	17.8
	Manure	3.420	52	56	59	....	3.5	6.75	....
	Manure and lime	3.140	54	59	62	....	3	5.1	19.5
	Lime	3.060	52	54	59	....	5.6	9.75	....
	Cowpeas	3.000	47	53	56	....	4.5	9.8	....
	Check	3.230	50	56	62	....	3.5	6.75	25
	Check	....	45	54	57	....	....	....	....

[1] Not planted.

The different fertilizers in conjunction with plant growth had different effects in the different soils. In the case of Frankstown stony loam the crop growth and the fertilizers had little effect on the catalytic power. In the case of Takoma lawn soil, manure and lime made a considerable increase in the total amount of oxygen evolved over the unplanted and planted checks. In case of Amarillo silt loam, the general trend of the effect of crop growth and fertilizer was to quicken the rate of catalysis slightly. In the case of Westmoreland clay the limed soils were the better catalyzers. In the case of the Dekalb silt loam, the soil containing lime and manure was the best catalyzer. It may be seen from the preceding table that the treatment which gives the best growth does not necessarily give the greatest catalysis of the hydrogen peroxide.

EFFECT OF LIMING AND PLANTING ON THE CATALYTIC POWER.

To test the effect of lime on the catalytic power, wheat was grown in pots of Clarksville silt loam, fertilized with different ratios of the fertilizer salts (sodium nitrate, potassium sulphate, and acid calcium phosphate) so that the soil contained 50 pounds per acre of NH_3, K_2O, P_2O_5, or mixtures of these, and the limed portion in addition 2,000 parts of calcium carbonate per million of soil. The wheat was grown three weeks and the green weight of the plants was taken, and the soils were thoroughly sifted from roots, etc. After the soils had become air dry, the catalytic power was tested in the usual manner. As may be seen in the following table, the limed soils had a slightly quicker rate of catalysis. Whether the effect of liming on the catalytic power of the planted soil was direct or indirect is not known.

TABLE VII.—*Effect of lime on the catalytic power of a planted soil.*

Soil and treatment.	Ratio P-N-K.	Quantity of oxygen evolved in—		Time to evolve 40 c. c. of oxygen.	Time to evolve 50 c. c. of oxygen.
		7 minutes.	15 minutes.		
Clarksville silt loam, Kentucky:		*C. c.*	*C. c.*	*Minutes.*	*Minutes.*
Limed	10- 0- 0	67	68	0.91	1.33
Not limed		67	68	.97	1.4
Limed	3- 3- 4	70	71	.91	1.3
Not limed		68	69	1.13	1.6
Limed	0-10- 0	57	57	1.33	2.2
Not limed		56	56	1.71	2.9
Limed	0- 0-10	64	64	.97	1.5
Not limed		60	60	1.37	2.25
Limed	Check.	60	60	1.08	1.6
Not limed		62	62	1.23	2.0

EFFECT OF MOISTURE CONTENT ON THE CATALYTIC POWER.

In the case of oxidation by soils, the oxidizing power was increased by increase of water to optimum water content. To test the effect of moisture on catalysis, the water was added to each soil until the percentage of water based on the dry weight of the soil was 16. The soils were kept in this condition for two weeks and equivalent amounts of the moist and dry soils were compared. An increase in the moisture content of the soil decreased rather than increased the catalytic power, as may be seen in the following table:

TABLE VIII.—*Effect of moisture on catalytic power of soils: (A) moist soil, (B) air-dried soil.*

Soils.	Quantity of oxygen evolved in—				Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.		
	C. c.	*C. c.*	*C. c*	*C. c.*	*Minutes.*	*Minutes.*
Sassafras silt loam:						
A	7	10	11	11	....	....
B	9	12	16	18	....	....
Clarksville silt loam, Tennessee:						
A	55	60	61	61	5.3	12
B	56	62	62	62	4.5	9.75
Hagerstown loam:						
A	50	56	56	56	6.8	....
B	57	63	63	63	5.2	8.75
Hagerstown loam and manure:						
A	50	56	56	56	7	....
B	50	60	63	63	7	14
Arlington clay loam:						
A	15	22	28	33	....	....
B	15	22	27	33	....	....
Sassafras clay loam:						
A	6	11	13	15	....	....
B	7	15	26	38	....	....

This effect of moisture would seem to throw out the possibility that the power of these soils to decompose hydrogen peroxide is due to a soluble catalase.

ACTION OF POISONS ON THE CATALYTIC POWER.

Carbon bisulphide.—May and Gile[1] found that the addition of 0.1 c. c. of carbon bisulphide to 5 grams of soil greatly depressed the catalytic power of Porto Rican soils. Accordingly, as in their experiments, 0.1 c. c. of carbon bisulphide was added to 5 grams of soil and the soil was well shaken. After the odor of bisulphide was no longer noticeable a test was made. The following table gives the results:

TABLE IX.—*Effect of carbon bisulphide on the catalytic power of soils: (A) check soil, (B) soil treated with carbon bisulphide.*

Soils.	Quantity of oxygen evolved in—			Time to evolve 60 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	
	C. c.	*C. c.*	*C. c.*	*Minutes.*
Hagerstown loam plus complete fertilizer:				
A	50.5	59.5	60	17.25
B	48	56	56	....
Hagerstown loam plus lime and manure:				
A	54	60	60	10.5
B	64	67	67	4.5
Hagerstown loam plus lime:				
A	59	63	63	7
B	52	54	54	....
Clarksville silt loam:				
A	72	74	76	3
B	81	81	81	1.75

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[1] Loc. cit.

TABLE IX.—*Effect of carbon bisulphide on the catalytic power of soils: (A) check soil, (B) soil treated with carbon bisulphide*—Continued.

Soils.	Quantity of oxygen evolved in—			Time to evolve 60 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	
	C. c.	*C. c.*	*C. c.*	*Minutes.*
Sharkey clay:				
A	52	65.5	65.5	9.5
B	49	53	53	....
Volusia silt loam:				
A	27	41	55	46
B	13	21	30.5	....
Hagerstown loam plus manure:				
A	57	65	67	8.6
B	56	63	63	9
Orangeburg loam:				
A	65	66	66	1.8
B	64	65	65	1.75
Woodland soil, Reading, Conn.:				
A	55	63	63	10.8
B	53	62	63	10
Dutchess loam:				
A	39	54	63	23.5
B	35	50	59	34.6

The table shows that the carbon bisulphide has a retarding effect on the amount of catalysis and considerably reduces the rate in most cases. In two cases, Hagerstown loam plus lime and manure and Clarksville silt loam, treatment with carbon bisulphide greatly increased the catalytic power of the soil. It would seem that the catalytic power of soils is due to different causes in different soils.

Mercuric chloride.—Mercuric chloride has a greater retarding action on catalysis than carbon bisulphide. When added to soil in the proportion of 0.5 c. c. of a 1 per cent solution to each 5 grams of soil mercuric chloride markedly decreases the rate of catalysis, in some cases to less than half the rate of the untreated soil. The effect of the mercuric chloride on the absolute amount of oxygen evolved is not marked and in two cases, Orangeburg loam and Clarksville silt loam, Kentucky, it had practically no effect on the rate. With increasing amounts of mercuric chloride, the rate of catalysis is in general still further lessened.

Hydrocyanic acid.—Hydrocyanic acid checks the catalytic power of both the enzyme β-catalase and the inorganic colloidal solutions. Upon Loew's insoluble α-catalase it had little action. To test the effect of the hydrocyanic acid on soils 10 c. c. of a 2 per cent solution of the acid were allowed to stand over night on 5 grams of soil which had recently come to the laboratory from the field. To the check soils 10 c. c. of distilled water were added. Then 5 c. c. of full strength neutralized hydrogen peroxide were added and the oxygen collected with the results as shown in Table X.

TABLE X.—*Effect of hydrocyanic acid on total amount of oxygen evolved and on rate of evolution: (A) check soil, (B) soil treated with hydrocyanic acid.*

Soils.	Quantity of oxygen evolved in—							Time to evolve 40 c. c. of oxygen.	Time to evolve 50 c. c. of oxygen.	Time to evolve 60 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	90 minutes.	140 minutes.	300 minutes.			
Hagerstown loam plus manure:	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*Min.*	*Min.*	*Min.*
A	42	55	60	62	63	64	64	6.5	10.75	29.5
B	5	10	18	29	38	45	55	98.5	155	....
Hagerstown loam plus complete fertilizer:										
A	44	55	58	58	58	58	58	5.75	10	....
B	7	15	25	38	47	53	59	65	124	....
Hagerstown loam plus lime and manure:										
A	53	59	60	60	60	60	60	4.5	5.8	20
B	23	40	54	61	61	61	62	14.75	22.7	49.5
Hagerstown loam plus lime:										
A	50	57	58	59	59	59	59	4.3	7	....
B	26	44	57	63	64	64	64	12.8	19	37
Orangeburg loam:										
A	60	62	62	63	63	64	64	2.25	2.9	6.5
B	36	49	53	59	64	65	65	8.25	16.7	45
Woodland soil, Reading, Conn.:										
A	38	54	60	61	61	60	60	7.5	11.3	23.7
B	6	12	22	38	47	52	60	64	104	180
Dutchess loam:										
A	27	41	54	62	62	62	62	13.8	23.5	44.8
B	4	9	17	28	34	42	43	122.5	....	....
Volusia silt loam:										
A	11	19	28	38	44	52	58	71	130	....
B	1	3	5	10	12	15	16	....	....	....
Clarksville silt loam:										
A	59	61	61	62	61	60	60	2.6	3.8	7.2
B	36	52	58	61	60	59	59	8.25	13.2	37.3
Amarillo silt loam soil:										
A	22	34	42	48	50	51	52	23.6	84	....
B	.5	.5	.7	.8	.8	2.2	3	....	....	....
Amarillo silt loam subsoil:										
A	21	32	41	47	50	51	51	28.6	83	....
B	.5	1.3	2.3	4.4	6.3	7.9	8.5	....	....	....
Dekalb silt loam soil:										
A	28	41	48	51	51.1	51.5	51.8	14.5	42.5	....
B	2	3	5.5	9	12	17	19	....	....	....
Dekalb silt loam subsoil:										
A	3	5	8	12	14	19	27	....	....	....
B	......	......	......	......	......	......	......	....	....	....
Frankstown stony loam soil:										
A	43	52	55	55	55	55	55	5.5	11	....
B	6.5	15	26	37	42	45	48	72.3	....	....
Frankstown stony loam subsoil:										
A	4	7	11	16	19	23	25	....	....	....
B	......	.2	.3	.8	.9	1.5	2	....	....	....

The hydrocyanic acid greatly retarded the catalysis but did not completely destroy the catalytic power. In soils like the Amarillo silt loam, soil and subsoil, Dekalb silt loam, subsoil, and Frankstown stony loam, subsoil, the hydrocyanic acid brought the catalytic power practically to a standstill.

In order to find out whether or not the soil recovered from the effect of the hydrocyanic acid three soils, a fair catalyzer, a good catalyzer, and a very good catalyzer, Volusia silt loam, Hagerstown loam, manured, and Orangeburg loam, respectively, were treated with 10 c. c. of a 2 per cent solution of hydrocyanic acid and were then spread out and exposed to draft from an electric fan until air dried and kept in air six days with frequent sifting until the odor of hydrocyanic acid was no longer detectable and no test for cyanide could be obtained in the water extract. Then the air-dried soils which had been treated with the hydrocyanic acid were compared as regards their catalytic power with nontreated air-dried soils, and it was found that the injurious action of the hydrocyanic acid still persisted. The retarding effect of hydrocyanic acid seems to be due then not to the formation of a surface film as suggested by Bredig and Ikeda [1] and Kastle and Loevenhart,[2] but rather to its chemical action on soil constituents.

Hydrogen sulphide.—Schönbein [3] found that plant juices instantly lost their catalytic power upon coming in contact with hydrogen sulphide. Bredig and von Berneck [4] pointed out that hydrogen sulphide greatly retarded the catalytic action of platinum on hydrogen peroxide and in medium concentration, $\frac{M}{3450}$ practically brought the catalytic action of the platinum to a standstill. Loew [5] showed that soluble catalase of tobacco was injured by saturated aqueous solution of hydrogen sulphide but was not destroyed by it. To test the effect of hydrogen sulphide on the catalytic power of soil, 5 grams of soil were exposed to the gas in a bell jar for one hour. Then, after exposure to the air for 2 hours, the catalytic power of the soil was tested.

As in the case of platinum and the enzyme catalase, hydrogen sulphide has a great inhibiting action on the catalytic power of soils, a greater effect, in fact, than carbon bisulphide and mercuric chloride.

Phenol and alcohol.—According to Bredig and von Berneck,[5] phenol has little retarding effect on the catalytic action of platinum. In the case of soils, phenol has a varying effect. In some soils it has a slight retarding action, in others it retards considerably. In the case of Clarksville silt loam it had no effect whatever and in the case of Orangeburg loam it quickened the rate of catalysis slightly. Alcohol had practically no effect on the amount of oxygen evolved and reduced the rate of catalysis only to a moderate degree.

Hydrocyanic acid, mercuric chloride, carbon bisulphide, and hydrogen sulphide check the catalytic power of nonenzymotic substances as well as the catalytic power of the enzyme catalase. Accordingly the experiments with these anticatalytic substances throws little light on the nature of the catalytic power of soils, although from the fact that the catalytic power persists to a considerable degree in the presence of these antienzymotic substances especially in the presence of mercuric chloride and carbon bisulphide, it must be concluded that the catalytic power is due at least in part to other factors than the enzyme catalase. How much of the catalytic power of the soils is to be attributed to the various factors may be brought out by other experiments.

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[1] Zeit. phys. Chem., **37**, 1 (1901).

[2] Amer. Chem. Jour., **29**, 397 (1903).

[3] Jour. prakt. Chem., **89**, 340 (1863).

[4] Zeit. phys. Chem., **31**, 258 (1899).

[5] Loc. cit.

EFFECT OF HEAT ON THE CATALYTIC POWER.

Dry heat.—To test the effect of dry heat on the catalytic power of the soils, 5 grams of soil were placed in the air oven at 105° C. for an hour. Then 10 c. c. of 1½ per cent neutralized hydrogen peroxide were added to the soil and the oxygen collected in the usual manner. The results are shown in Table XI.

TABLE XI.—*Effect of dry heat 105° C. on the catalytic power of soils: (A) check soils, (B) heated soils.*

Soils.	Quantity of oxygen evolved in—				Time to evolve 50 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	
	C. c.	*C. c.*	*C. c.*	*C. c.*	*Minutes.*
Hagerstown loam plus manure:					
A	49	57	57	57	7.6
B	39	47	49	49	....
Hagerstown loam plus complete fertilizer:					
A	48	55	55	55	8.5
B	43	56	58	59	10.2
Hagerstown loam plus lime and manure:					
A	56	57	57	57	4
B	56	57	57	57	4.3
Hagerstown loam plus lime:					
A	60	61	61	61	3
B	55	57	57	57	5.25
Hagerstown loam untreated:					
A	53	59	59	59	5.5
B	44	55	56	56	10.25
Clarksville silt loam, Tennessee:					
A	57	64	65	65	5
B	55	61	61	61	5.3
Sharkey clay:					
A	53	60	60	60	6
B	54	61	61	61	5.6
Volusia silt loam:					
A	26	39	51	57	28
B	9.0	15	20	24	....
Dutchess loam:					
A	45	53	61	62	13
B	34	44	57	63	20
Woodland soil, Reading, Conn.:					
A	58	61	62	62	5
B	14	22	32	39	159
Orangeburg loam:					
A	61	61	61	61	1.2
B	63	64	64	64	1.2
Frankstown stony loam:					
A	60	65	65.7	65.8	4.8
B	43	58	64	64	10
Amarillo silt loam soil:					
A	53	63	74	75	5.6
B	46	59	73	75	9.2
Amarillo silt loam subsoil:					
A	55	63	65	65.5	5.2
B	51	62	66	67	7.5

The effect of dry heat is in general to lessen the catalytic power of the soil. In some soils, as may be seen in the table, dry heat had practically no effect on catalysis, while in others it caused a marked decrease in the catalytic power. In general, the results from dry soils agree with those of May and Gile, who found that heating for one-half hour at 100° C. destroyed only two-tenths of the active amount of catalase, and that heating for several hours diminished the activity less than half. From the fact that in certain cases, such as Volusia silt loam, the decomposition of the hydrogen peroxide goes on for a certain length of time and to a certain degree and then stops entirely suggests that, contrary to our expectation, the decomposing power is not due to catalase, but rather to definite chemical substances which are more or less destroyed or changed by heat. The retarding effect both of heat and of substances which check catalysis is more noticeable in soils which have naturally only a slight catalytic power.

Steam heat.—The soils in tubes plugged with cotton were heated in a steam sterilizer for 1 hour and 15 minutes. Then the catalytic power was tested in the usual manner.

The effect of steam heat in reducing the catalytic power of the soils is only slightly greater than that of the dry heat.

Heating under pressure.—Heating the soils in an autoclave for one hour at a pressure of 10 atmospheres had a marked inhibiting action on the catalytic power of the soil, as the following table shows:

TABLE XII.—*Effect of heating under pressure on the catalytic power of soils: (A) check soil, (B) heated soil.*

Soils.	Quantity of oxygen evolved in—				Time to evolve 50 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	
	C.c.	*C.c.*	*C.c.*	*C.c.*	*Minutes.*
Hagerstown loam plus manure:					
A	47	56	59	60	8.5
B	6	9	13	17	....
Hagerstown loam plus complete fertilizer:					
A	50	59	60	61	7
B	5	9	14	23	....
Hagerstown loam plus lime and manure:					
A	55	57	57	57	4.25
B	17	25	32	35	....
Hagerstown loam plus lime:					
A	60	64	65	65	4.75
B	13	19	26	30	....
Hagerstown loam untreated:					
A	49	58	59	59	7.6
B	8	13	19	24	....
Clarksville silt loam, Tennessee:					
A	50	56	57	57	6.8
B	4	9	11	11	....
Sharkey clay:					
A	56	58	58	59	4.75
B	6	9	18	34	....
Volusia silt loam:					
A	27	41	51	55	27.5
B	4	4	4	4	....
Amarillo silt loam soil:					
A	62	65	65	65	3.4
B	39	46	51	53	21
Amarillo silt loam subsoil:					
A	56	64	66	66	5.5
B	40	52	59	62	13
Frankstown stony loam:					
A	62	64	64	65	3.2
B	7	11	16	23	....
Dutchess loam:					
A	44	58	63	63	10
B	18	24	33	45	....
Woodland soil, Reading, Conn.:					
A	50	57	57	57	7
B	6	8	11	17	....
Orangeburg loam:					
A	60	60	60	60	1.4
B	56	60	60	60	4

Catalase has been reported in plants and in microorganisms. Naturally it would be expected to be in soil. If, however, the catalytic power of the soils tested by us is due to an enzyme, the enzyme must have a wonderful resistance to heat, since soils heated to 180° C. in the autoclave for one hour still have considerable catalytic power. Guisti[1] found that heating in an autoclave to 133° C. destroyed the catalytic power of all microorganisms, while it has been found[2] generally that plant catalase is less resistant. As shown by Loew both α and β catalase are destroyed by heating to 75°–80° C.

Ignited soils.—König and his coworkers and likewise May and Gile found that ignited soils had very little power to decompose hydrogen peroxide. To study the effect of ignition, the soils in the following table were weighed out and were heated to a red heat. When cold the catalytic power was determined. As the table shows, the ignited soils had, as a rule, a fair decomposing action on the hydrogen peroxide, a stronger action for the most part than did the same soils steam-heated under pressure. Only five soils suffered a marked loss of catalytic power, namely, Sharkey clay, Volusia silt loam, Amarillo silt loam, Amarillo silt loam, subsoil, and Woodland soil.

TABLE XIII.—*Effect of ignition on the catalytic power of soils: (A) normal soil, (B) ignited soil.*

Soils.	Quantity of oxygen evolved in—				Time to evolve 50 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	
	C. c.	*C. c.*	*C. c.*	*C. c.*	*Minutes.*
Hagerstown loam plus manure:					
A	50	59	61	61	7
B	29	43	55	62	21.6
Hagerstown loam plus complete fertilizer:					
A	53	61	62	62	6
B	31	45	55	60	19.3
Hagerstown loam plus lime and manure:					
A	57	58	58	58	3.6
B	45	57	57	57	10
Hagerstown loam plus lime:					
A	63	64	64	64	3
B	55	61	61	61	5.3
Hagerstown loam:					
A	53	59	61	61	5.3
B	31	45	55	55	20
Clarksville silt loam, Tenn.:					
A	49	55	56	56	7.3
B	30	42	51	54	26
Sharkey clay:					
A	64	68	68	68	3
B	8	16	26	39	....
Volusia silt loam:					
A	30	44	57	62	21
B	6	10	17	24	....
Amarillo silt loam, soil:					
A	62	65	68	65	3.4
B	9	15	23	34	135
Amarillo silt loam, subsoil:					
A	56	64	66	66	5.5
B	6	12	22	36	112
Frankstown stony loam:					
A	62	64.8	64.8	65	3
B	19	29	41	54	48

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[1] Annali di Medicina Navale, 10, II, 213 (1908).

[2] See Die Katalase. F. Battelli and L. Stern. Ergebnisse der Physiologie, 10, 546 (1910).

TABLE XIII.—*Effect of ignition on the catalytic power of soils: (A) normal soil, (B) ignited soil*—Continued.

Soils.	Quantity of oxygen evolved in—				Time to evolve 50 c. c. of oxygen.
	7 minutes.	15 minutes.	30 minutes.	60 minutes.	
	C. c.	*C. c.*	*C. c.*	*C. c.*	*Minutes.*
Dutchess loam:					
A	44	58	63.3	63.8	10
B	38	54	63	65	12.3
Woodland soil, Reading, Conn.:					
A	50	57	57	57	6.9
B	4	6	9	14	....
Orangeburg loam:					
A	60	60	60	60	1.4
B	44	53	58	58	11

The catalytic power of the ignited soils is due altogether to the inorganic constituents. In the normal soil the catalytic power is due only in part to the inorganic matter, since heating in the autoclave under pressure, a treatment which greatly decreases the catalytic power, would not make much change in the inorganic matter, as compared with the organic matter of the soil, and would most probably destroy the enzyme catalase if it were present. Incinerating the soil would convert some of the salts to oxides and would make the medium slightly alkaline, conditions which favor the decomposition of the hydrogen peroxide.

EFFECT OF INCREASING TEMPERATURES ON THE CATALYTIC POWER.

Soils were kept one hour at temperatures ranging from 30° to 140° C. Then after cooling to the room temperature, the rate of catalysis was tested. The results are shown in Table XIV.

TABLE XIV.—*Effect of increasing temperature on the rate of catalysis. The catalytic power of all soils was tested at room temperature.*

Soil.	Time required to evolve 50 c.c. of oxygen at—						Temp. of maximum rate.
	30° C.	65° C.	95° C.	110° C.	125° C.	140° C.	
	Min.	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	° C.
Dekalb silt loam	5	4.2	5.8	7.2	16	20.5	65
Frankstown stony loam	3	3	4.8	6.1	10	14.7	30-65
Hagerstown loam plus manure	5	5.7	7	6	21	17.2	30
Clarksville silt loam	1.7	1.2	1	1.5	2.2	3.1	95
Amarillo silt loam	6	4.7	5.6	5.8	13	7.1	65
Woodland soil, Reading, Conn	4.1	4.5	13.8	22	71.5	51.3	30
Volusia silt loam	57	89	180	....	....	....	30
Dutchess loam	9.7	10.5	14.8	18	20.7	21	30-65
Orangeburg loam	.83	1.0	.91	1.3	1.1	1.1	30-95
Hagerstown loam plus lime	2.5	1.8	2.6	3.2	3.1	2.6	65
Hagerstown loam	1.8	2.2	2.8	3.4	3.3	3	30

In the case of the Dekalb silt loam, Hagerstown loam plus lime, Clarksville silt loam, and Amarillo silt loam, heating to 65° and cooling again to room temperature increased the catalytic power of the soils. Heating to 110° in the case of Amarillo silt loam and Clarksville silt loam increased the rate of catalysis, while heating Hagerstown loam plus lime to 95° had no decreasing action on the catalytic power. The effect of heating the soil must have been upon the organic matter of the soil, since heating in this way would have no effect on the inorganic matter and would affect the catalase injuriously rather than otherwise. In the case of Orangeburg loam, heating to 140° C. had little effect on catalysis, so in this soil also there is little probability that the catalytic power is due to catalase. In the case of the six other soils, it is possible that the catalytic power is due to catalase, though in no case was there a total destruction of the catalytic power. Even in cases where heat retarded there is a secondary quickening of the rate of catalysis, in that the rate of catalysis, though slow, is greater after the soils have been heated to 140° C. than it is after they have been heated to 125°. In the case of the Hagerstown loam plus manure, heating to 110° has practically no retarding effect.

Catalytic power at different temperatures.—The catalytic power of the six soils which had their catalytic power lessened by heating to 65° for one hour was next tested at temperatures from 0° C. to 90° C. The soil and the hydrogen peroxide were brought to the desired temperature before the peroxide was added to the soil. The results are shown in the following table:

TABLE XV.—*Effect of increasing temperatures on the rate of catalysis, i. e. the time required to evolve 50 c.c. of oxygen. The catalytic power was determined at the temperature indicated.*

Soil.	Time required to evolve 50 c.c. of oxygen at—									
	2° C.	10° C.	20° C.	30° C.	40° C.	50° C.	60° C.	70° C.	80° C.	90° C.
	Min.	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*
Hagerstown loam plus manure	10.1	6.7	3.1	2.1	1.2	1.1	1.1	0.6	0.5	0.2
Dutchess loam	132	60	33.2	14.7	10.3	5	3.3	2.5	1.3	.86
Frankstown stony loam	25.6	14	6.6	3.2	2.3	1.7	1.20	.64	.49	.51
Orangeburg loam	4.3	2.88	1.9	1.5	.60	.36	.32	.19	.14	.09
Volusia silt loam, virgin soil:										
A	84	47	35	27.7	23.7	32	36	28	7	2.5
B	148	70	58	54.9	52	(1)	(1)	34.6	12.3	3.7
Volusia silt loam, planted soil.	170	53	36.5	27.7	25.7	21	16.7	8.6	5.4	2

[1] At 50° and 60° no 50 c.c. reading could be obtained, so the readings are given for 40 c.c. (A) and 50 c.c. (B) for the series 2°-90° for Volusia silt loam, virgin soil. In the case of this soil the catalytic power both as regards the total amount of oxygen evolved and the rate of evolution is less at 50° and 60° than at 30°. From 0° to 40° the rate of catalysis is quickened. From 40° to 60° there is a falling off in the rate. Above 60° the rate of catalysis is again markedly quickened.

It may be seen from the table that the rate of decomposition of the hydrogen peroxide by the soil is quickened by increasing the temperature with an exception of a break in the case of Volusia silt loam, virgin soil, and that no optimun temperature is apparent. The increased catalytic power with increase of heat up to 90°, beyond which temperature the experiment was not carried, indicates that the catalytic power of these soils is not due to the enzyme catalase, unless the soil strongly protects the catalase from the injurious action of heat. The catalytic power of the eleven soils of Table XIV and Table XV seems to be due then not to enzymotic activity but to the organic and inorganic constituents of the soil.

That inorganic substances would act catalytically has long been known. The catalytic power of inorganic material was early pointed out by Thénard, and especially by Schönbein, and has been studied in detail by Bredig and his co-workers. Recently it has been pointed out by Bordas and Touplain[1] that colloidal ferrous oxalate or ferric lactate are found to give all the catalytic reactions of curdled milk.

CATALYTIC POWER OF SOILS AS RELATED TO THE MANGANESE CONTENT.

The catalytic power of a number of soils analyzed for their inorganic content by W. O. Robinson of this bureau were tested for their catalytic power. The catalytic power stood in very little relation with the Fe_2O_3 content, but did stand in close relation with the manganese content, estimated as MnO, as may be seen in the following table:

TABLE XVI.—*Catalytic power of soils in relation to their manganese content.*

Soils.	Content of MnO.[a]	Order of MnO content.	Order of catalysis 5 grams soil.	Order of catalysis 10 grams soil.	Time to collect 50 c.c. oxygen from 10 grams soil.	Quantity of O_2 collected from 10 grams soil in 60 minutes.
	Per cent.				*Minutes.*	*Cu. cen.*
Cecil clay soil	0.305	1	1	1	0.9	61
Decatur clay loam soil	.070	2	2	2	2.25	63.5
Decatur clay loam subsoil	.053	3	3	3	7.3	61
Cecil clay subsoil	.031	4	7	8	....	16.5
Cecil sandy loam soil	.029	5	5	5	97	41
Volusia silt loam subsoil	.026	6	6	6	....	24.5
Cecil sandy loam subsoil	.018	7	12	12	....	5.5
Durham sandy loam soil	.017	8	10	11	....	10
Durham sandy loam subsoil	.014	9	9	9	....	13
Volusia silt loam soil	.012	10	4	4	19.6	58
Norfolk sandy loam soil	.008	11	8	7	....	23.8
Norfolk sandy loam subsoil	.004	12	11	10	....	11

[a] Analyses by W. O. Robinson of this bureau, made in connection with a general study of inorganic soil constituents of prominent soil types, the results of which will be published later.

That the catalytic power of the soil is correlated to some degree with the manganese content of the soil is evident. It is the form of manganese rather than the absolute amount since Volusia silt loam with a small manganese content is a much better catalyzer than Cecil clay subsoil with two and one-half as much MnO, and since further, the addition of manganese salts, such as chloride, carbonate, sulphate, and dioxide had no effect in increasing the catalytic power of soils. Some other factors than the total amount of manganese must be the determinants in producing the catalytic power of the soils. These factors are the nature of the manganese compound or the nature of the associated organic matter.

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[1] Compt. rend., 150, 341 (1910).

CATALYTIC POWER OF SOILS AS RELATED TO THE ORGANIC CONTENT.

In regard to the organic matter of the soil it may be said that König found that the catalytic power of the soils studied by him and his associates was in almost exact relationship to the humus content. In our work this relationship does not seem to obtain. Thus in Table XVI the best catalyzer, Cecil clay, has much less organic matter than Cecil sandy loam, which is a rather weak catalyzer. Further, in samples of Hagerstown loam from the plot experiments of the Pennsylvania State Experiment Station, which had been under the same treatment for a number of years, the limed and manured soil and the limed soil had a much smaller humus content and a considerably greater catalytic power, as may be seen in the following table. The humus was determined by extracting 20 pounds of soil with 15 liters of 2 per cent caustic soda[1] and precipitating the solution with dilute hydrochloric acid.

TABLE XVIII.—*Catalytic power of samples of Hagerstown loam of different humus content.*

	Hagerstown loam.	Hagerstown loam plus lime.	Hagerstown loam plus lime and manure.	Hagerstown loam plus complete fertiliser.	Hagerstown loam plus manure.
Humus content, in grams	43.63	11.33	5.53	30.50	30.33
Number of minutes required to evolve 50 c. c. of oxygen	7.6	4.75	4.25	7.0	8.5

As shown in Tables XI and XII the samples of Hagerstown loam as well as other soils had their catalytic power reduced by heating for one hour at 105° C. and especially by heating in an autoclave for an hour under a pressure of 10 atmospheres. It is obvious that the organic matter plays some part in the decomposition of hydrogen peroxide since the dry heating would have practically no effect on the inorganic matter and heating in the autoclave would have little effect on the inorganic as compared with the organic matter which suffers great change. It is the nature of the organic matter and not the absolute amount that is of importance.

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[1] See The Forms of Organic Nitrogen in plats 20-24. B. E. Brown and E. C. Lathrop. Report Penn. State College. 1909-10. 118.

CATALYTIC POWER OF ORGANIC SUBSTANCES.

Since no reference could be found relative to the action of definite organic substances on hydrogen peroxide, a number of organic compounds, 70 in all, were tested. Of these compounds, solanine, darkened pyridine, and darkened piperidine, especially the latter, possessed the direct power to decompose the hydrogen peroxide. Samples of solanine which had been exposed to the air but a short time had no action on the hydrogen peroxide until nicotine was added. Colorless pyridine likewise had no action on hydrogen peroxide. It would seem that the catalytic power of the organic compounds was due to a change brought about by partial oxidation as in the case of the old sample of solanine and the partially oxidized pyridine and piperidine. Pyridine, colorless or colored, has a slight activating action on the catalytic power of manganese dioxide while darkened piperidine greatly increases the power of manganese dioxide to decompose hydrogen peroxide. In the vast complex of organic matter of the soil it is to be expected that bodies would be present which would exercise a direct action on the hydrogen peroxide or an indirect action in activating other compounds, organic or inorganic, as the case may be.

As yet no catalyzing agent has been extracted from soils. In the case of Clarksville silt loam, however, there was isolated from the coarse sand from the mechanical analysis of this soil a considerable amount of black particles. These particles decomposed hydrogen peroxide, liberated chlorine from hydrochloric acid, and consisted undoubtedly of manganese dioxide. In the case of Volusia silt loam, Frankstown stony loam, and Sassafras silt loam no manganese dioxide was isolated by the mechanical separation method. Manganese dioxide alone, however, has by no means the same action on hydrogen peroxide as has a soil containing an equivalent amount of manganese calculated as MnO.

If the heat resisting catalytic power of soil is due to catalase, which must arise from plant or microorganisms, our conclusions must be like those of May and Gile, that the catalytic power of the soil is a rough measure of the combined quantity of bacteria and organic matter present in the soil. Unless the soil has a great protective power against the injurious effect of heat on enzymes, however, it would seem that the catalytic power of the soils studied by us is not due to an enzyme but rather to the inorganic and organic matter, working separately, conjointly, or in activating combinations in which the inorganic matter, especially manganese, is the active complement and the organic matter the activating complement.

The part that microorganisms play in the formation of activating substances and of compounds directly capable of decomposing hydrogen peroxide is undoubtedly very great, but can not be considered in detail here.

SUMMARY.

Soils possess the power to decompose hydrogen peroxide. This power is greater in soil than in subsoils, in strong vital soils than in weak soils. It persists for years in air-dried soils.

Though good production is not dependent on the catalytic power, the presence of a strong catalytic power in a soil can be taken as a priori evidence that the many factors making for soil fertility would be prominent and that the soil would be a productive soil.

The catalytic power is checked to some degree by carbon bisulphide, mercuric chloride, and especially by hydrocyanic acid, which in some cases practically destroys it.

Heating in an autoclave under pressure of 10 atmospheres retards the catalytic power, though dry heat for one hour at 105° has little depressing action.

Various inorganic substances and several organic compounds, especially those in a state of partial oxidation, have the power of decomposing hydrogen peroxide, while several organic compounds increase the catalytic power of manganese dioxide.

In general the catalytic power of soils seems to be due not to an enzyme, such as catalase, but rather to the inorganic and organic matter working separately, conjointly, or in activating combination.

Issued December 17, 1912.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—Bulletin No. 87.

MILTON WHITNEY, Chief of Bureau.

NITROGENOUS SOIL CONSTITUENTS AND THEIR BEARING ON SOIL FERTILITY.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., April 29, 1912.

Sir: I have the honor to transmit herewith the manuscript of a scientific paper entitled "Nitrogenous Soil Constituents and their Bearing on Soil Fertility," by Dr. Oswald Schreiner, in charge of Soil Fertility Investigations, and Mr. J. J. Skinner, of this bureau. The results of this investigation throw much light upon the problems of soil fertility, and I therefore recommend its publication as Bulletin No. 87 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FIGURE.

FIG. 1. Triangular diagram, with the points representing the 66 culture solutions numbered 21

NITROGENOUS SOIL CONSTITUENTS AND THEIR BEARING ON SOIL FERTILITY.

INTRODUCTION.

For some years past a survey of the organic matter of the soil from the standpoint of biochemistry has been under way. The object has been to determine definitely as many constituents of the soil as possible, and while this was tedious in the beginning, as no methods of any kind existed for such work, the results have nevertheless been very promising in the last year or two, and as many as 35 different compounds have been isolated and identified. The definite recognition of these compounds has led to a fuller understanding of the chemistry of the organic matter of soils and of the biochemical changes taking place therein. It is not the purpose of the present bulletin to enter into this phase of the discussion, but rather to confine itself closely to the effect which a certain group of these soil constituents have on plant growth. It should be mentioned, however, that the compounds isolated cover a wide range of chemical substances of biological origin. They are represented by the hydrocarbons, consisting or carbon and hydrogen only, by oxygenated compounds like the acids, fats, resins, alcohols, esters, and waxes, consisting of carbon, hydrogen, and oxygen, as well as by a large group of nitrogenous compounds that consist of carbon, hydrogen, oxygen, and nitrogen. These nitrogen compounds contain the nitrogen combined in different forms, as, for instance, with carbon only, as the amino group NH_2, or as the imino group NH. Most of the compounds isolated from the soil are decomposition products of proteins, nucleo-proteins, nucleic acids, lecithins, and similar complex nitrogenous compounds of biological origin.

The nitrogenous soil constituents isolated or determined in this laboratory up to the present time are: Creatinine, with the probability that creatine also exists; hypoxanthine, xanthine, guanine, adenine, choline, histidine, arginine, nucleic acid, and picoline carboxylic acid. The chemistry and method of isolation and identification of most of these are fully described in other bulletins.[1] The present bulletin is chiefly concerned with their effect on crops.

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[1] Buls. Nos. 53, 74, 83, 88, and 89, Bureau of Soils, U. S. Dept. of Agr.

As many as possible of these and related compounds have been studied in regard to their effect on plant growth, in most cases quite extensively. The first soil nitrogen compound studied in respect to its effect on plants was found to be moderately harmful. This was the picoline carboxylic acid studied in 1907. Since then the above isolated nitrogenous compounds have been thoroughly studied in respect to their effect on growth, and the results uniformly show a more or less marked beneficial effect. This will be shown in this bulletin, as will also the fact that the plant absorbs these and other organic soil constituents and is affected by them in its life functions beneficially or adversely, as the case may be.

DISCUSSION OF THE RESULTS.

DIRECT ABSORPTION OF ORGANIC SOIL CONSTITUENTS.

There can be little, if any, doubt that organic constituents of the soil or nutrient solution are absorbed directly by the roots of plants and enter into the cells, reacting with the cell contents and producing effects which differ according to the nature of the compound absorbed. By this direct absorption is meant, not the simple absorption occasioned by the replacement of the liquid lost by the plant through transpiration, as is the case in the transfusion of certain dyes in plants when immersed in dye solutions, but rather the physiological absorption by passage through the membranes of the cell wall. The function through which plants absorb organic soil constituents is in every respect similar to that exhibited by plants with the mineral nutrients. In order to prevent misunderstanding in regard to what we mean by direct absorption of organic soil constituents, it will be well to discuss here briefly the absorption from the soil waters of mineral nutrients by plants, as this subject is by no means as clear as it should be and because a clear understanding of this is also necessary for the correct interpretation of the analytical results in this work.

Many writers in agricultural literature seem to be under the impression that the only way that a plant can get the nutrients from a solution is to use all the water it can in building tissue and to lose the remainder by transpiration, so as to obtain the necessary nutrients dissolved in the soil water or nutrient solution. In other words, that the plant maintains a current of water entering at the root as the nutrient solution and leaving the plant as pure water at the leaf surfaces, that is, by transpiration or evaporation. From their arguments it follows that if a half-strength solution is presented to the plant it will have to take up and transpire twice as much water to obtain the same nutrients. In other words, the plant is supposed to absorb the mineral constituents in the same concentration as the solution in which the roots bathe. This is, however, not in accordance with the facts. The plant has greater difficulty in obtaining the mineral elements from the weaker solution, but it does not accomplish this by expending the extra energy involved in transpiring double the amount of water. It accomplishes the same end through the process of absorption, by which it is able to take in each cubic centimeter of water that it absorbs a greater concentration of minerals than is contained in the original solution, with the result that the original culture or soil solution becomes weaker in these constituents, that is, the solution loses its mineral nutrients faster than it does its water. For this reason culture solutions must be frequently changed in experimental work if the concentration is to be maintained within reasonable limits, and in the case of the soil solution in situ it must be resupplied by solution from the store of fertilizer elements in the soil or by movement of the solution itself, and possibly also by movement of the root by growth into new territory. In our own cultural work we found it desirable to make the change of solution at least every three days, as in this time a considerable change had taken place in the 80 parts per million concentrations used. For instance, the loss of water from a 250 c. c. solution during this 3-day period is only about 10 per cent, whereas the analysis of the solution after supplying this water showed the mineral nutrients to be reduced from 80 to as low as 23.8 parts per million, or a decrease of 70 per cent.[1] It is obvious that the plants have taken the nutrients faster than the water, and this under conditions of good growth.

Not only does the absorbing power of the root enable the plant to take more nutrients per cubic centimeter of water absorbed than is contained in the same volume of the soil solution, but it also enables the plant to obtain a different ratio of the mineral nutrients for its use than exist in the nutrient solution.[2]

These facts are extremely important, as they show that the absorbing power of the plant is not regulated by the amount of transpiration, but rather by the life processes within the plant and the requirements of these life processes. While the plant possesses the power to absorb more readily those constituents it needs in its metabolism, it is, nevertheless, not able to wholly exclude undesirable or useless constituents, and thus it happens that it even absorbs those which interfere with its growth or normal development.

The purpose of the above presentation in regard to absorption of mineral nutrients by plants from soil or culture solution is to make clear that the process is connected with and is a part of the general metabolic processes of plants, that the absorbed material did not get into the plant wholly as the result of its happening to be in the water absorbed, but is absorbed faster, and in some cases slower, than this water, and that when it passes through the membranes possessing these properties of absorption it reacts on the cell contents in a favorable or unfavorable manner, as the case may be, influencing, at any rate, the life processes of the plant itself. This kind of absorption might well be called physiological absorption to distinguish it from the other similar terms used in soil and plant work.

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[1] Bul. 70, Bureau of Soils, fig. 5.

[2] This fact is made clear by fig. 7 and the accompanying text in Bureau of Soils Bulletin No. 70.

This property of plants to absorb the mineral constituents from the soil solution is held by us to be in nowise different in respect to the soluble organic constituents of the soil solution, and this, it is believed, will be amply shown in the present bulletin.

That plant roots can affect organic substances externally has been repeatedly shown by the work in this laboratory and elsewhere, and it is therefore possible that organic substances may also influence the plant itself through this external action. It was shown, for instance, in Bulletins Nos. 56 and 73 that organic substances could be acted upon by the oxidizing power of the root. The yellow aloin is changed to red, the colorless phenolphthalin to red, the colorless compounds α-naphthylamine, benzidine, etc., to colored compounds deposited on the exterior of the root. Even the harmful but colorless compound vanillin was changed to a purple compound deposited on the root, the solution itself becoming weaker and weaker in vanillin, and finally losing its harmful property. It must therefore be granted that through such an external action the plant itself may be affected in its normal development. In the great majority of cases, however, that have come under our observation it must be concluded that the organic substance is absorbed—it certainly disappears from solution in such cases as can be tested—and does not produce its effects until after it has entered the plant cells, there reacting with the contents of the cells and thus affecting the normal life process of the plant, favorably or unfavorably, as the case may be.

In the case of the soil constituent dihydroxystearic acid the normal metabolism is greatly disturbed.[1] From this point of view its effect has not been fully studied biochemically, but enough has already been learned of its action to fully substantiate the statement that the metabolism of the plant is forced out of the normal. This is strikingly shown by the decreased absorption of plant nutrients, although these were present in the culture solution in plentiful amounts in perfectly soluble form; further, that a differentiation in the absorption of the separate nutrients, phosphate, potash, and nitrate, was brought about, a proportionately greater nitrate consumption being evident with the plants affected by dihydroxystearic acid. It would seem that such a change in plant metabolism could only be explained on the assumption that the soil compound produced a reaction within the plant itself, after absorption from soil or nutrient solution.

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[1] See Bul. No. 70.

The specific effects produced by organic compounds must also be taken into consideration. Some of the compounds studied have produced a more marked effect on plant roots than on the green parts of plants. For instance, vanillin affects roots more than tops, dihydroxystearic acid affects both roots and tops, while pyridine and picoline affect the green parts more than the roots. While the action on the roots might possibly be explained on the assumption of exterior action, the effect on the tops is not readily explainable in this manner, especially not in those cases where the roots are left entirely normal while the tops are injured. This is perhaps most strikingly illustrated by those cases where specific results are produced by the organic substances. One of these is the action of cumarin. This compound has so specific an effect that the experimenter can pick out cumarin-affected plants at a glance. The greatly stunted tops, with short broad leaves and much distorted and thickened stems of the wheat seedlings, are very characteristic. In strong contrast to this action of cumarin is the action of quinone, which produces long, thin, slender plants, equal in size to the normal growth, but considerably less in weight. This different reaction of the plant to these two compounds must be due to the direct absorption of the compound accompanied by a disturbed metabolism.

This, in fact, is made more probable by the behavior of the plants in regard to the simultaneous absorption of nutrient minerals. The cumarin-affected plants absorbed relatively more phosphate, the quinone plants relatively more potash. Moreover, the plant growth, and presumably the general metabolism, was rendered more normal in the case of the cumarin-affected plants by the addition of phosphate, in the case of the quinone-affected plants by the addition of potash. In the case of the soil constituent dihydroxystearic acid this more normal development was produced by the addition of nitrate.

A still better illustration that an organic compound is absorbed by plants, producing strongly marked changes in its metabolism and physiological behavior, amounting practically to what might be termed a physiological disease of the plant, is found in guanidine, given in this bulletin. The roots in this case are apparently unaffected. The green parts of the plants are affected by small spots of a bleached appearance, which develop and spread, ultimately producing a weakened plant, the leaves of which break at the stem, wilt, and die. The phenomenon is not unlike that produced by disease. This effect of guanidine is only explainable on the assumption of its absorption by the plant and its action on the normal metabolism or function of the plant protoplasm.

The cases cited are sufficient to show that organic substances, like inorganic poisons, such as the heavy metals, for instance, are absorbed by plants and react with the protoplasm of the plant.

DIRECT ASSIMILATION OF ORGANIC SOIL CONSTITUENTS.

The physiological effects mentioned in the last section indicate that the substances worked within the plant. The physiological effects there cited are mainly detrimental to growth and to proper functions of the plant. There are, however, many organic substances that exhibit no detrimental effect, but rather produce an increase in growth and altogether a better plant development. The compounds studied and found to have this beneficial property have been almost entirely nitrogenous compounds and the question of their direct use by the plant is an important one on account of the importance of nitrogen in plant metabolism. The isolation and discovery of organic nitrogen compounds in soils made a study of their properties in this respect absolutely necessary and the results obtained throw much light upon the question of the relationship between soil organic matter and crop growth.

WHEN NITRATES ARE ABSENT.

Creatinine has a beneficial effect on growth. Its solutions in pure water produced an increased growth over plants growing in pure water without creatinine. A more extended study showed that when combined with phosphate and potash this nitrogenous soil constituent gave in solution cultures an increased growth. This increased growth was observed in each and every culture, no matter what the proportion of potash and phosphate. The average effect in such cultures was an increase in plant growth of 36 per cent. This increase in growth must be ascribed to creatinine, and, like the effects produced by the detrimental compounds after absorption by the plant, these beneficial effects should be attributed to action within the plant after absorption. It is certain that creatinine disappears from solution in the course of the experiment, as we were able to trace its diminution in the course of three days from 50 parts per million to 5 parts per million, using the method of Folin for this purpose. The next question considered was its change to creatine, which would not have responded to this test. Boiling with hydrochloric acid, which would revert the creatine to creatinine, failed, however, to reveal any increase in the creatinine content of the culture solutions; hence this possibility is excluded. Tests made by means of the delicate nitrite reagent of Griess, gave only negative results, and tests for nitrate by means of the phenoldisulphonic acid test likewise showed the absence of any nitrate.

Ammonia was tested for by means of Nesslers reagent, and while not completely absent, only traces were found, which, however, was also the case in the control cultures. It follows that the creatinine had not changed to creatine, but had disappeared from solution without the production of nitrite, nitrate, or ammonia, and hence must have been absorbed by the wheat plants as such, whatever its fate may have been after absorption.

Moreover, if the change had been one to creatine, this would not have explained the increased growth any better, although it would have explained the diminution of creatinine in the cultures. For creatine, when tested, behaved in exactly the same manner as creatinine toward plants, producing in solution cultures, with potash and phosphate added, an increase of 44 per cent, again without the production of nitrite, nitrate, or ammonia.

Furthermore, the formation of nitrate is practically excluded in solution cultures of this kind, and ammonia, if formed, would not have had an effect even approximating that produced by these soil constituents in the solution cultures.

In the case of all the other compounds studied the solution cultures were tested for nitrites, nitrates, and ammonia, and always with the same result, total absence of nitrites and nitrates, and only traces of ammonia, except in one case. This was leucine, which apparently decomposes readily, with the formation of ammonia. It is noteworthy and significant in this connection that the leucine culture solutions containing the ammonia had only a very moderate effect on plant growth, far less than those produced by creatinine or the other soil compounds studied.

Histidine and arginine, both of which are protein decomposition products of the soil, showed this same increase in plant growth, potash and phosphate being already present; the increase was 30 and 33, respectively. Nucleic acid, and its nitrogenous decomposition product, hypoxanthine, likewise showed an increase of 74 and 41 per cent, respectively. The other xanthine bases, xanthine and guanine, while not so completely studied, show, nevertheless, the same behavior as do also several other nitrogenous compounds not yet found in soils, notably, asparagine, which produced an increase of 47 per cent.

WHEN NITRATES ARE PRESENT.

The above results were obtained by the addition of compounds to the solutions containing phosphate and potash, but no nitrate, so that the compounds were the only source of nitrogen. When nitrates were also present the addition of the compounds produced a further increase in growth, but this was not as marked as when no nitrate whatever is supplied. For instance, in the culture series in which 8 parts per million of NH_3 as nitrate was present, the compounds mentioned above produced the additional growth of 17 per cent with creatinine, 11 per cent with creatine, 14 per cent with histidine, no increase with arginine, 23 per cent with nucleic acid, 14 per cent with hypoxanthine, and 14 per cent with asparagine. It is obvious that the additional effect attributable to the organic compounds is not as great when some nitrate is supplied. As more nitrate is supplied the effect in the cultures containing the organic compounds becomes still less noticeable.

If this were the only information at hand, one would be justified in concluding that the plant absorbed and utilized the organic compound only when it could not get nitrate, and that when this is supplied in sufficient quantity the compound is rejected, or at least not utilized. This supposition is, however, negatived by two experimentally determined facts. First, that in the case of creatinine, where such a test was possible, this compound was shown to disappear from solution fully as fast from those cultures which contained plenty of nitrates as from those which contained none, thus showing that under both conditions the creatinine was absorbed by the plants. Second, by the results of the analyses of the nutrient solutions during growth. These analyses established the fact that the plants consumed more nitrate when the nitrogenous compounds were absent than they did when the compounds were present. This behavior was shown by all of the above compounds. It seems from this that the plants absorb and use such nitrogenous soil constituents whether nitrate be present or not, the effect on growth being much more marked in the limiting case, where no nitrate was present, and that in the other cases the compounds replaced the effect of nitrate in producing growth.

CHEMICAL CONTROL OF EXPERIMENTS.

It will be clear from the above remarks that the culture work was throughout under strict chemical control, so as to establish as definitely as possible that the effects on the plants noted were produced by the absorption of the compounds as such. Nitrite, nitrate, or ammonia were tested for and found to be absent, or, in the case of ammonia, in traces only, and the removal of the compound itself was substantiated by chemical tests when this was possible. Although neither nitrate, nitrite, nor ammonia was found, the plants, nevertheless, grew remarkably well and the only conclusion justified by this experimental evidence is that these compounds are directly absorbed and assimilated. With the strict chemical control exercised, all possibility of any extended action by bacterial or other external biological agencies seems excluded. If such effects were produced in these experiments, they were of only minor significance in the results obtained. Bacteria and other microorganisms were excluded as far as possible, but no special effort was made to maintain absolutely sterile conditions, inasmuch as this would have been a practical impossibility in experiments on so large a scale, involving over a thousand plants in a single test. Moreover, it may even appear questionable whether absolute sterility, as being too artificial a condition for the determination of the effect of soil constituents on plants, would be desirable.

It would seem that chemical control under as normal conditions as a cultural experiment will allow, is better than conducting the experiment under the artificial condition of sterility, which, after all, is made only so that biochemical changes be excluded. In our experiments the bottles were sterilized before being used in making culture solutions for the various changes, the pans and other apparatus used in germinating the seed were sterilized from time to time, and corks used for the cultures were always clean and sterilized before use. Although all of these precautions were taken, it was of course not possible to exclude some microorganisms in such work, as the solutions were exposed from time to time to the air. There was no excessive microorganic life noticeable with the single exception of the leucine cultures already mentioned. While bacteria and other microorganisms were present in the solutions to a slight extent, it can hardly be said that their influence could have been large; that is, such influence as they had was probably so slight as to be negligible so far as the general and larger tendencies which are shown in this bulletin to exist are concerned. Moreover, some very excellent data with sterile pea cultures have recently been obtained by Hutchinson and Miller,[1] which led these investigators to the conclusion that some organic nitrogen compounds were available as sources of nitrogen, even under sterile conditions. Their method of experimentation was necessarily different from that used by us and was usually confined to the growth of two pea plants in culture solutions under sterile conditions, the nitrogenous compounds being added to the culture solutions and the weighed plant analyzed, the increase in total nitrogen being thus determined. Proceeding in this way, they found that acetamide, urea, barbituric acid (with calcium carbonate), and alloxan, are good sources of nitrogen, while formamide, glycocoll, α-aminopropionic acid, guanidine, hydrochloride;[2] cyanuric acid, oxamide, and sodium aspartate are not so good. Several other compounds were doubtful or even toxic.

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[1] Hutchinson, H. B., and Miller, N. H. J. The direct assimilation of inorganic and organic forms of nitrogen by higher plants. Centralbl. f. Bakt., 30 513 (1911).

[2] In our own work guanidine as carbonate is shown to be a strong poison to plant metabolism in the case of wheat, corn, potatoes, and cowpeas. The peculiar effect of guanidine, namely, to produce bleached spots, seems also to have occurred in the case of peas in the experiments of Hutchinson and Miller for they mention that "the guanidine plants were the first to lose their color."

EXPOSITION OF THE MANNER IN WHICH THESE SOIL COMPOUNDS ARE USED.

The soil compounds beneficial to growth—creatinine, creatine, histidine, arginine, hypoxanthine, nucleic acid, as well as others—are among the unit parts of which the complex constituents of every life cell are built; that is, they are the units obtained when one of the complex proteins, nucleo-proteins, etc., are resolved into simpler compounds by chemical means. Take, for instance, a nucleo-protein. This complex can be split into a protein and a nucleic acid. The protein can be further split into a number of smaller units which are known as splitting products of protein or primary degradation products. These units, or bricks out of which the complex structure of the protein is built, comprise such compounds as histidine, arginine, lysine, and others still simpler in composition. This process of taking the complex molecule apart into these units is accomplished by fairly simple means. To effect further decomposition of these units means more deep-seated changes, an actual breaking up of the bricks themselves, as it were. In this process ammonia, acids, phenols, and the like are formed. In the soil, as is well known, the ammonia is again changed to nitrite and nitrate, and thus, according to most authorities, the nitrogen cycle is completed and ready to start again on its mission of producing plant protein.

Let us also trace the "building down" of the nucleic acid, which was one of the component parts of the nucleo-protein used above as an illustration. Like the protein part, nucleic acid yields smaller parts or bricks. The unit bricks of the structure of nucleic acid comprise such compounds as hypoxanthine, xanthine, guanine, adenine, cytosine, pentose sugars, phosphoric acid, and others. All of those mentioned have been found in soils in the investigations of this laboratory. Like the splitting products of the proteins, these compounds can and do suffer further decomposition in the soil, the nitrogen appearing first as ammonia, then nitrite, and nitrate as before; but again these changes mean the breaking up of the unit bricks which composed the nucleic acid structure.

The proteins, nucleo-proteins, and nucleic acid are essential to all animal and vegetable growth. That the plant can build these compounds with nitrate and ammonia as the source of the nitrogen has been definitely shown for a long time. In the case of the animal it is just as certain that it can not build up tissue with nitrate or ammonia as the source of nitrogen. The animal obtains its nitrogen for protein building from the organic nitrogen compounds of plants or other animals. Hence has arisen the popular conception that plants build up complex protein compounds from mineral salts, and from mineral salts only; that is, that plants differ fundamentally in their functions from animals.

The animal in order to obtain the elements for building its own protein, resolves by the process of digestion the protein materials of ingested vegetable or animal food into the units or bricks above mentioned and then builds out of these units its own protein. If, in a restricted diet, certain of these units are excluded, improper nutrition results. All of the units must be potentially in the food of the animal or be formed in the digestive tract.

While the plant is able to build up the complex protein substances in its tissues from nitrate and even ammonia, it does not make this complicated chemical transformation in one step. While this process is but little understood, it is certain that there must be intermediate products, and that these are the same products as the degradation units above mentioned is more than probable. Many of these, such as histidine, arginine, asparagine, guanine, xanthine, etc., have been found in plant tissues as such, and lately also creatine and creatinine in this laboratory. It seems logical, therefore, that if the plant absorbs such units of tissue building from the soil that it uses them just as if they were produced within the plant itself. Nitrate (NO_3) presents nitrogen in a highly oxidized form. The nitrogen in organic combination in the plant is always in a greatly reduced form, as NH or NH_2 groups or even attached directly to carbon only. It follows that much energy must be expended in causing this chemical transformation. This energy can be expended otherwise, and hence plant efficiency is increased and growth augmented when the plant obtains compounds which will serve as tissue builders directly from the soil.

The results obtained in the cultural work with such nitrogenous soil constituents lead us to suggest this theory in explanation of their action when alone and in conjunction with nitrate, namely, that the compounds are absorbed as such and utilized directly for building up the proteins and the other complex nitrogenous constituents of vegetable material. It seems reasonable to suppose that the unit parts of the complex protein molecules, when presented to the plant, will be used by it in preference to expending energy on the nitrate to prepare these units. If a soil be liberally supplied with all these units, it is conceivable that good plant growth will result, even without nitrate. If only a limited amount or kind of the units be present, the plant must have nitrate with which to supply the missing units.

In the light of this theory, it is clear that a single compound or brick can not be used to build the whole structure. Nitrate is, therefore, required for maximum effect, so that other compounds or units can be formed. It is, of course, conceivable, and this conception forms a part of this theory, that the plant enzymes may be able to transform one of these units into other closely related units, such as, for instance, the change from guanine or adenine to xanthine and hypoxanthine, respectively by deamidizing enzymes,[1] so that if guanine only were presented to the plant it would by virtue of such an enzyme, have available both guanine and xanthine, as well as ammonium compounds. If, however, only a single compound or brick is supplied, in the absence of other sources of nitrogen, there should be a limit beyond which the plant can make no further use thereof, because of the fact that the entire protein structure can not be thus built up. Such a limit seems, in fact, to be reached when a single compound is presented to the plant, as is shown by the following experiment.

A series of culture solutions containing 25, 50, 100, 200, and 400 parts per million of histidine as carbonate were prepared. Each culture of the series contained 32 parts per million of P_2O_5 as calcium acid phosphate and 48 parts per million of K_2O as potassium sulphate. A second series contained creatinine and a third series contained asparagine, the concentrations of these compounds ranging as before from 25 to 400 parts per million. Wheat plants were grown and the solutions renewed every three days. The plants grew from December 21, 1911, to January 3, 1912. The green weight obtained with wheat seedlings in these culture solutions are recorded in Table I.

TABLE I.—*Effect of histidine, creatinine, and asparagine, used in varying concentrations.*

Culture number.	Concentration in p. p. m.	Green weight of culture in—		
		Histidine.	Creatinine.	Asparagine.
		Grams.	*Grams.*	*Grams.*
1	Nutrient solution (control)	1.200	1.200	1.200
2	Nutrient solution+25	1.440	1.650	1.410
3	Nutrient solution+50	1.750	1.800	1.600
4	Nutrient solution+100	1.980	1.790	1.540
5	Nutrient solution+200	2.040	1.720	1.540
6	Nutrient solution+400	1.920	1.610	1.560

It will be noticed that growth was increased by all these compounds with increasing concentration up to 50 or 100 parts per million, beyond which practically no further increase took place. The plants were getting all the histidine, creatinine, or asparagine that they could economically use when 50 to 100 parts per million were presented in the culture solution. A concentration of 150 parts per million can therefore be considered as fully covering the maximum effect to be obtained from any one of these compounds in such an experiment.

The next step, therefore, was to prepare culture solutions as above but containing 150 parts per million of each of these substances, and another culture solution which again contained 150 parts per million,

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[1] See in this connection Jones and Austrian, Zeit. physiol. Chem., 48,110 (1906); Jour. Biol. Chem., 8, 227 (1907).

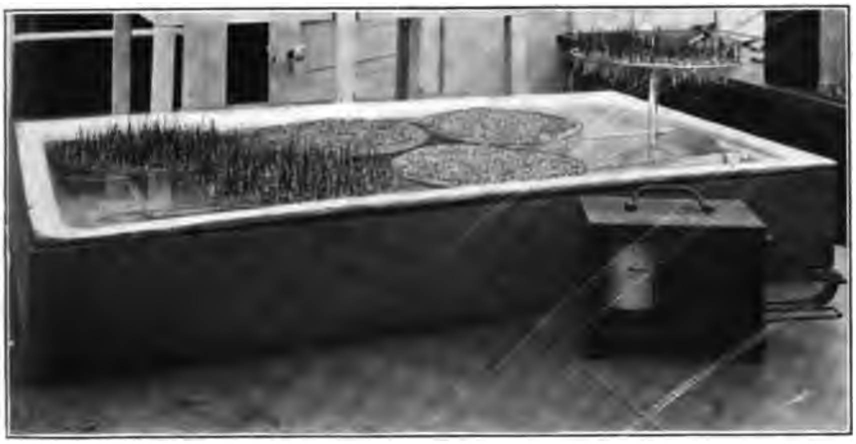


FIG. 1.—METHOD OF GERMINATING MANY THOUSAND SEEDLINGS ON PERFORATED ALUMINUM PLATES FLOATED ON THE SURFACE OF WATER BY MEANS OF A SEALED GLASS TUBE RAFT IN A PORCELAIN-LINED TANK.

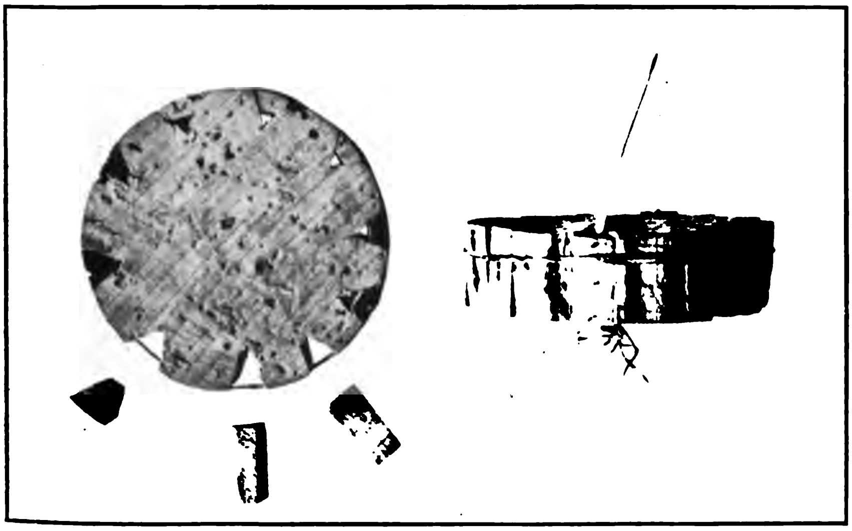
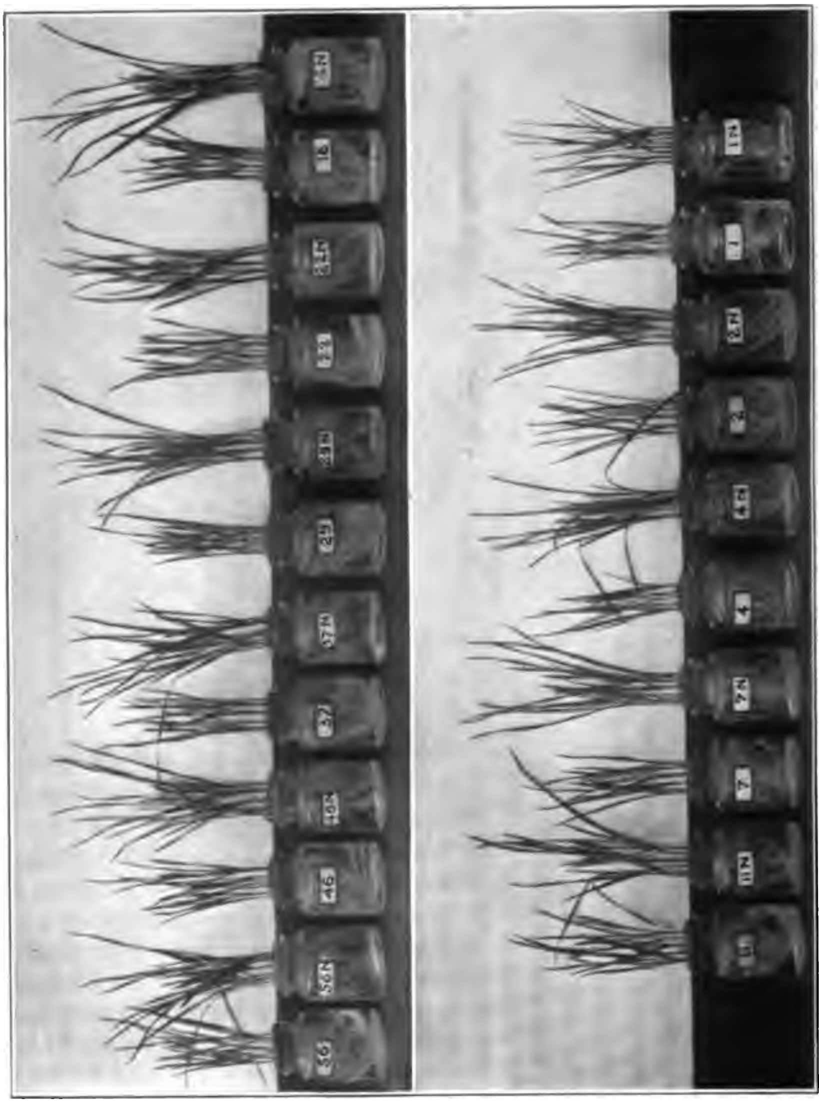


FIG. 2.—METHOD OF MOUNTING THE SEEDLINGS IN THE NOTCHED CORKS.



BENEFICIAL EFFECT OF NUCLEIC ACID, AN ORGANIC SOIL CONSTITUENT, IN CULTURE SOLUTIONS OF DIFFERENT COMPOSITION.

[Cultures marked N contain nucleic acid.]

but this time composed of 50 parts per million each of histidine, creatinine, and asparagine. This mixture of the three compounds was then tested against the equivalent concentration of the compounds separately. The plants grew from January 10 to 23, 1912. The green weights are given in Table II.

TABLE II.—*Effect of histidine, creatinine, and asparagine, used singly and in combination.*

Culture number.	Culture solution.	Green weight.
		Grams.
1	Nutrient solution (control)	1.172
2	Nutrient solution+histidine, 150 p. p. m	1.640
3	Nutrient solution+creatinine, 150 p. p. m	1.575
4	Nutrient solution+asparagine, 150 p. p. m	1.350
5	Nutrient solution+ {histidine, 50 p. p. m creatinine, 50 p. p. m asparagine, 50 p. p. m}	1.900

It will be seen that histidine, creatinine, and asparagine again increased growth, and in the order named, but that when all three were combined, although only one-third the amount of each was present, the growth was nevertheless greater than the best of these. In the light of the theory above expressed, this would mean that the three different units were more useful to the plant than an equivalent amount of any one kind.

The nitrogen content in these solutions bears no relation to the plant growth observed. The nitrogen content of the histidine culture was 40.6 parts per million, of the creatinine culture it was 55.8 parts per million, and of the asparagine culture it was 31.8 parts per million. The culture of all three compounds had 42.8 parts per million. It was, therefore, greater than the asparagine culture, approximately the same as the histidine, and considerably less than the creatinine culture, while in growth it was greater than any of these. Moreover, it is evident from a glance at Table I that there exists no relation between nitrogen content and growth in regard to these different compounds. Creatinine culture No. 2, for instance, containing 9.3 parts per million nitrogen, gave a growth which was not even equaled by a nitrogen content as high as 84.8 parts per million in the asparagine culture No. 6. The differences in the action of these compounds, either singly or in combination, is, therefore, due to an inherent property in the compounds themselves which makes it impossible for any one wholly to replace the other in plant metabolism.

APPLICATION OF THE RESULTS TO SOIL AND FERTILIZER STUDIES.

Nitrogenous compounds of biological origin exist in soils, and most of those here discussed are distinctly beneficial to crop growth. It follows that their presence in soils is beneficial to crops, inasmuch as the crop can use them, without first changing to ammonia, nitrite, or nitrate, by further decomposition and synthesis. They appear to be as beneficial as nitrate and were able to replace the latter in part. It follows that a mere nitrate determination in the soil does not give a complete valuation of its readily assimilable nitrogen, for it is conceivable that nitrification may be low and yet appreciable quantities of such beneficial nitrogenous compounds as histidine, hypoxanthine, creatinine, etc., be present. To alone lay stress on the nitrate content in soils is obviously erroneous in the light of these results, although it is not unlikely that their formation also goes hand in hand with the production of these cleavage or splitting products of protein.

The nitrogenous fertilizers, such as dried blood, tankage, fish scrap, etc., as well as the leguminous crops, as green manure, are excellent sources of these compounds. To some extent they are already contained in such fertilizers, but especially are they formed during the process of decomposition in the soil. The results in this bulletin make many field observations with such fertilizing material clear, and show that the decomposition does not have to go on so far as to change all nitrogen to ammonia and nitrates before such nitrogenous material becomes useful for plant growth. These facts are of further significance in that such compounds are removed from the soil with the greatest difficulty by drainage waters, whereas nitrates are easily lost in this way if the plant does not remove them as fast as formed. Nitrates do not last over from season to season, but the organic compounds can do so and yet be ready for absorption and use by plants at any time. In this form the nitrogen of the soil is conserved, whereas excessive nitrification or even ammonification may result in actual loss of the soil nitrogen by leaching.

The nonsymbiotic or symbiotic nitrogen fixing bacteria also furnish just such compounds to soil and plants, and thus some light is thrown on the effect of nodules in increasing so largely the growth of those plants on which they occur. While the actual process of fixing the nitrogen is but little understood, it is certain that compounds of the nature of those here discussed are formed in the nodules. It is to be regretted that so little attention has been paid to the chemical nature of the nodules. The numerous investigations made have confined themselves to the determination of total nitrogen and ash constituents. Stoklasa, however, has found asparagine in such nodules, and Sana[1] has found glycocoll in addition to asparagine. A more extended investigation will doubtless disclose other compounds of this nature. Both of these constituents are directly absorbed by plants, and produced increased growth in our experiments. It would seem logical to conclude that such compounds, produced by organisms in the nodules, pass from these to the plants as such, and in harmony with the theory proposed in this bulletin, are used directly for the production of more complex protein matter in the plant, just as is done when such constituents are absorbed from solution or soil by plant roots or produced within the plant itself from nitrates. These compounds in nodules may, therefore, serve a similar function in the direct nutrition of the plant by the nodules as that performed by them when present in soil.

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[1] Journ. Chem. Soc., 98, II, 993 (1910).

BENEFICIAL AND HARMFUL NITROGENOUS COMPOUNDS.

In the foregoing there has been presented in a general way the action of those nitrogenous compounds which were beneficial to plants, and the details of the investigations on which this was based will be presented in the following sections of this bulletin. It must not be inferred, however, that because the compounds discussed were nitrogenous that all were found to be beneficial in our work, for this is not the case. The soil constituent picoline carboxylic acid is moderately harmful and the related uvitonic acid decidedly so. Tyrosine, a splitting product of protein, is toxic to plants, and neurine is decidedly so. Picoline, piperidine, and pyridine are likewise toxic. Guanidine is shown to be decidedly harmful to plants and to produce a very marked effect on its metabolism, producing symptoms like those of a disease.

The beneficial nitrogenous compounds are not equally beneficial, and likewise the toxic compounds are not equally toxic. There is, in fact, every gradation between the best and the worst of these, a number of compounds being intermediate and possessing neither property strongly—that is, having practically no noticeable effect. The compounds can not be arranged in the order of their effectiveness, and no rule concerning their action which can be based on their chemical composition is available in our present state of knowledge. It is, nevertheless, possible to classify them, although roughly, into beneficial or harmful. A group, in which neutral and doubtful members would have to be put, is, however, necessary if all the compounds studied are to be included. Such a classification has been made and is appended to this bulletin.

There have also been included other organic compounds which have been studied in regard to their effect on plants in this laboratory, as well as allied compounds tested by other investigators, only the experiments with higher plants being considered. No attempt at completeness has been made, although all the more modern and important work is included. We have confined ourselves (1) to compounds found in soils in the investigations of this laboratory; (2) to compounds likely to occur in soils, but not yet found—that is, certain plant constituents or their decomposition products; (3) compounds related to any of these, as well as some compounds which, for one reason or another, have been often tested with higher plants in laboratory or field in agricultural studies. The simple amines, hydrocyanic acid, chloroform, ether, the phenols, and many other compounds on which the literature is very voluminous and the results often indefinite, have been excluded, and the reader is referred to standard textbooks on plant physiology for their action.

In the table the first column gives the name and formula of the compound, the arrangement being alphabetical. The second column gives the plant used in the test. The third column the effect of the compound on the plant, whether beneficial, harmful, or doubtful, or without effect. The fourth column gives the cultural method used; that is, whether solution, soil, or sand was used. In the last column appears some additional information regarding the tests.

In the second column, following the name of the plant used, is given a number which refers to a corresponding number in the reference list appended, giving the names of the investigators, the title of their papers, and the places of publication. There is also appended a very suggestive compilation of the occurrence of most of these constituents in plants, with a statement of their chemical relationships.

EXPERIMENTAL METHODS.

CULTURE SOLUTIONS.

In studying the effect of these nitrogenous soil constituents on growth, wheat seedlings were grown in aqueous culture solutions containing the ordinary fertilizer salts, calcium acid phosphate, sodium nitrate, and potassium sulphate. Some of the cultures contained calcium acid phosphate only, some sodium nitrate only, and some potassium sulphate only. Other solutions were composed of mixtures of two salts, sodium nitrate and calcium acid phosphate, sodium nitrate and potassium sulphate, and calcium acid phosphate and potassium sulphate. Still other solutions had all three constituents in various proportions. The concentration of all the solutions was 80 parts per million of the fertilizer ingredients, P_2O_5, NH_3, and K_2O. In cultures containing only one fertilizer salt—for instance, calcium acid phosphate—the concentration was 80 parts per million of P_2O_5. If two salts were present—for instance, calcium acid phosphate and sodium nitrate—the concentration was 80 parts per million of $P_2O_5+NH_3$. If all three salts were present, the concentration was 80 parts per million of $P_2O_5+NH_3+K_2O$. The ratios of these constituents varied in 10 per cent stages. In all there were 66 different cultures of nutrient solutions.

The triangular diagram is used as a guide. In this diagram (fig. 1) the apices, Nos. 1, 56, and 66, are the cultures which contain only the single salts, calcium acid phosphate, sodium nitrate, or potassium sulphate, respectively; that is, contain 100 per cent P_2O_5, NH_3, or K_2O, respectively. The line of cultures between 1 and 66 contains mixtures of P_2O_5 and NH_3 in 10 per cent differences; the line of cultures between 1 and 56 contains mixtures of P_2O_5 and K_2O in 10 per cent differences; the line of cultures between 56 and 66 contains mixtures of K_2O and NH_3. The cultures in the interior of the triangle contain mixtures of all three constituents, differing in 10 per cent stages, one from the other, the composition depending upon its position in the triangle, those nearer the P_2O_5 apex consisting chiefly of phosphate fertilizer, those nearer the NH_3 apex chiefly of nitrate fertilizer, and those nearer to the K_2O apex chiefly of potash fertilizer.

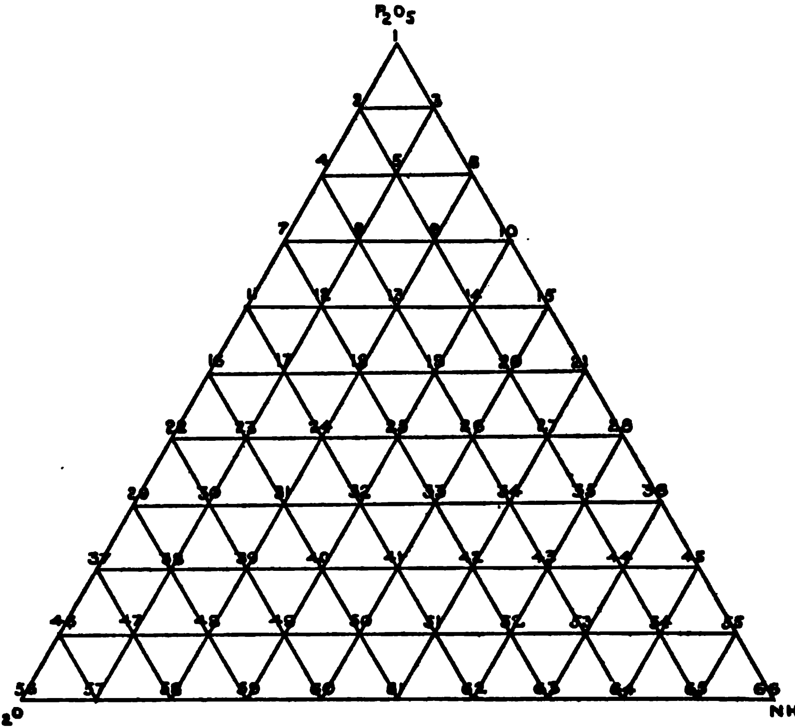

Fig. 1.—Triangular diagram, with the points representing the 66 culture solutions numbered.

As stated above, cultures in the line 1 to 56 contain no nitrate. The next line of cultures, namely, 3 to 57, contains throughout 8 parts per million of NH_3 as nitrate, but varying amounts of the other two constituents. Similarly the line of cultures 6 to 58 contains throughout 16 parts per million; line 10 to 59, 24 parts per million and so on until the culture No. 66 is reached, which contains 80 parts per million of NH_3 as nitrate, that is, no phosphate or potash. Likewise cultures in the line 1 to 66 contain no K_2O, but various amounts of P_2O_5 and NH_3; all cultures in line 2 to 65 contain 8 parts per million K_2O, and so on until culture No. 56 is reached, which contains 80 parts per million K_2O, and no nitrate or phosphate. Similarly cultures on line 56 to 66 contain no P_2O_5 but varying amounts of potash and nitrates; all cultures in line 46 to 55 contain 8 parts per million P_2O_5, and so on upward until culture No. 1 is reached, which contains 80 parts per million P_2O_5, but no potash or nitrate.

Two sets of cultures were prepared; to one set were added merely the nutrient salts, to a similar set the organic compound to be tested was added to each culture, usually in amounts of 50 parts per million, in addition to the nutrient salts. The culture solutions were contained in wide-mouth bottles, holding 250 c. c., and 10 wheat seedlings grown in each culture in a manner similar to that described in Bureau of Soils Bulletin No. 70. The culture solutions were changed every three days, four changes being made in the course of the experiment. The solutions were analyzed for nitrates immediately after each change. The phosphate and potassium were determined on a composite solution of the four changes. Observations on the general development of the plants and the effect on root growth and appearance were made during the experiment and photographs were taken. At the termination of the experiment the green weight was taken and recorded.

For the purpose of preparing the 66 culture solutions needed in this investigation, stock solutions of the three salts, calcium acid phosphate, sodium nitrate, and potassium sulphate, were prepared separately. The salts used were chemically pure salts, and were dissolved in each case in physiologically pure water. For the calcium acid phosphate solution 1.776 grams of $CaH_4(PO_4)_2.H_2O$ per liter were used. This solution has a concentration of 1,000 parts per million of P_2O_5. The sodium nitrate solution was prepared by using 5.000 grams of $NaNO_3$ per liter. This solution is equivalent to a concentration of 1,000 parts per million of NH_3. The potassium sulphate solution was prepared by dissolving 1.852 grams of K_2SO_4 per liter. This solution has a concentration of 1,000 parts per million of K_2O.

The amount of culture solution used in each culture bottle being 250 c. c., it follows that every 2 c. c. of these 1,000 parts per million stock solutions will represent 8 parts per million in the culture solution when this is diluted to the capacity of the bottle; i. e., the successive addition of 2 c. c. of the stock solution gives the 10 per cent differences desired in putting up the 66 solutions. In putting up the 66 cultures it was found desirable to calibrate each bottle for 250 c. c. capacity and to number them consecutively from 1 to 66. Bottles in which the 250 c. c. mark was either high or low, especially those which would submerge the seeds when filled, were discarded, only those being used which brought the surface of the liquid from one-half to one-fourth of an inch from the top.

These 66 bottles were then arranged in triangular form, as illustrated diagrammatically by figure 1.

The necessary amount of the 1,000 parts per million stock solution above described was measured from a burette. For instance, in adding the requisite amount of nitrate to the set of culture bottles, the line of bottles 1 to 56 received no nitrate solution, the line of bottles 3 to 57 received 2 c. c. each, the line 6 to 58, 4 c. c. each, and so on, increasing 2 c. c. with each successive line, the culture No. 66 finally receiving 20 c. c. of the nitrate solution. Likewise, in adding the requisite amount of potash, the cultures in line 1 to 66 received none, the cultures in line 2 to 65 received 2 c. c. each; in line 4 to 64, 4 c. c. each, and so on up to culture 56, which received 20 c. c. of the potash solution. The phosphate solution is added in the same manner, none to cultures in line 56 to 66, 2 c. c. to cultures in line 46 to 55, and so on up to culture 1, which received 20 c. c.

Each bottle received, therefore, a total of 20 c. c. of one, two, or three of the stock solutions, depending upon whether it was at the apex, along the sides, or in the interior of the triangle.

All of the cultures were then diluted up to the 250 c. c. mark.

In this investigation, as already mentioned, the culture solution usually contained 50 parts per million of the organic compound to be tested. The amount of this compound to be added to each culture bottle of 250 cubic centimeters was, therefore, 12.5 milligrams. Of the 250 cubic centimeters, 20 cubic centimeters were already contained in the bottles in the form of the fertilizer salt solution. Therefore, the solution with which the fertilizer salt solution in the bottles was to be diluted consisted of 12.5 milligrams of the compound dissolved in 230 cubic centimeters of pure water. A sufficient quantity of this strength of solution was prepared to fill the 66 bottles.

As a means of comparing the cultures grown in these solutions containing the organic compound, it was necessary to put up cultures prepared in exactly the same way, except that pure water was used for dilution.

In all of this work physiologically pure water was used. This was prepared by shaking ordinary distilled water with a highly absorptive carbon black, as described in earlier bulletins,[1] which removes from the water any injurious property it may possess.

The culture solutions were now ready to receive the plants which were thereafter grown in a greenhouse under suitable conditions.

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[1] Bul. No. 36, and Bul. No. 70, Bureau of Soils, U. S. Dept. of Agr.

GERMINATION OF SEEDLINGS.

In this work it was necessary to have a large number, often several hundred, and sometimes thousands of uniform seedlings; i. e., seedlings of the same age and equal in development and general vitality. The manner of growing the seedlings and the method of inserting them in the above culture solutions were as follows:

Perforated aluminum disks were floated, by means of a raft prepared from sealed glass tubing, in such a way that the disks were just kept at the surface of the water when loaded with seeds.

The wheat seeds, previously soaked in water, for about two hours, not longer, were spread evenly on the surface of the disks. The perforations in the 1.6 millimeter thick aluminum were approximately 3.2 millimeters in diameter and 2 millimeters apart. The entire arrangement of raft and disks was floated in a porcelain-lined iron tank 48 by 24 by 6 inches. Plate I, figure 1, shows this tank with several disks of seedlings at different stages of development. The seedlings were used when the plumule was about 1 inch high and just ready to emerge from the enveloping sheath. In this manner hundreds of uniform seedlings were obtainable.

CULTURE BOTTLES.

The bottles used in these cultures were made of flint glass, and were stoppered by means of a soft flat cork about 12 millimeters in thickness and notched for holding the seedlings, as shown in Plate I, figure 2. The method of notching these corks consisted in cutting 10 vertical, triangular wedges from its circumference with a circular saw driven by a small motor, or with a knife. Each wedge after being cut out was truncated, so that when replaced a small triangular opening was left through which the plumule of the seedling passed. This hole was large enough to hold the seedling firmly and yet not bruise or injure it in any way by pressure. Around the circumference of the cork, in the upper half, a groove had been made sufficiently large to hold a small rubber band. After the wedges were inserted, the band kept them in place and allowed the cork with the seedlings to be handled readily and put into or taken out of the bottle without disturbing the plants.

CHANGING THE SOLUTIONS.

As already mentioned, these solutions were changed every three days. This was done by putting up other triangles of bottles similar in every respect to those just described. The corks with the plants were then transferred from the old solution to the corresponding new solution. Since the old solution had lost some water by transpiration, it was again made up to 250 cubic centimeters and tightly stoppered, and was now ready for analysis. The amounts of phosphate, nitrate, and potash were determined. Three days later a similar change was made, and so on every three days to the termination of the experiment. Nitrate was determined immediately after making each change, but the phosphate and potash was determined on a composite of the four changes.

ANALYTICAL METHODS.

For the nitrate determination 10 cubic centimeters of each of the solutions was withdrawn and transferred to a Berlin porcelain evaporating dish bearing a number corresponding to that of the culture. The solutions were evaporated to dryness on a steam bath, being removed immediately when dry. After cooling, 1 cubic centimeter of the phenoldisulphonic acid reagent was added to each dish and well stirred with the rounded end of a glass rod, allowing the reagent to act about 10 minutes. The acid was then diluted with water and made alkaline with ammonium hydroxide. The yellow solution was then diluted to a convenient volume comparable to the intensity of the standard colorimetric solution, prepared at the same time, and was then compared with the latter in the Schreiner colorimeter. The results are stated in terms of NH_3 as this was the fertilizer designation used throughout the work. The details of this method are given in Bulletin No. 31, page 39.

The phosphate in the solutions was determined by the method described on page 46 of Bulletin No. 31, Bureau of Soils. In this method both the phosphate and silica are determined when the latter is present. In these experiments, however, the method was greatly simplified, inasmuch as repeated tests showed the almost total absence of silica from the solutions. As already mentioned, the glass containers used for these solutions were composed of very hard flint glass. In this case, therefore, the silica being zero, the two results obtained by this procedure were duplicates. In determining the phosphate, portions of the solutions were measured out in duplicate, 50 cubic centimeters in those cases where the weaker phosphate solutions were concerned and only 25 cubic centimeters in the case of the stronger solutions, the latter being, however, made up to 50 cubic centimeters before adding the necessary reagents. This was done to insure a sufficient amount of reagent to develop the full color. To one portion were then added 5 cubic centimeters of the nitric acid reagent and 4 cubic centimeters of the ammonium molybdate reagent, and the color read after 20 minutes in the colorimeter in comparison with a standard solution prepared at the same time. To the other portion only the ammonium molybdate reagent was added, allowed to stand one hour, and then the nitric acid solution added and after

20 minutes the color compared with the standard as in the previous case. As already stated, the intensity of the color in these two solutions was the same, thus showing the absence of silica. If silica had been present the intensity of the color developed under the two conditions would have been different and the amount of phosphate and silica, respectively, could have been calculated by means of the formula given in the original papers.

The potassium was determined by the colorimetric method of Cameron and Failyer,[1] given in detail in Bulletin No. 31, page 31. Electroquartz dishes were used in the investigation. Of the stronger solutions 10 cubic centimeters were used; i. e., those originally containing from 64 to 80 parts per million, 25 cubic centimeters of those containing from 32 to 64 parts per million, and 50 cubic centimeters of the weaker solutions.

To the solutions 0.5 c. c. of dilute sulphuric acid was added, and evaporated to dryness, the excess of sulphuric acid being driven off by heating over a naked flame. The last operation destroys any organic matter that may be present. To the cooled dish a few drops of hydrochloric acid and several drops of platinum chloride solution were added to slight excess. The residue was well worked with the rounded end of a short stirring rod and evaporated on a steam bath almost to dryness. The residue was then washed several times with alcohol and the washings poured through a carefully purified asbestos filter contained in a Gooch crucible. As much as possible of the residue was allowed to remain in the porcelain dish. After drying, the precipitate contained in the dish and in the Gooch crucible was dissolved in hot water, and, after cooling, one drop of hydrochloric acid and 0.5 c. c. of potassium iodide solution was added. A standard colorimetric solution of potassium platinic chloride was prepared at the same time and the solutions allowed to stand overnight for a full development of the color. The next morning they were read in the colorimeter.

STUDY OF THE EFFECT OF SOME NITROGENOUS SOIL CONSTITUENTS ON GROWTH AND ABSORPTION.

NUCLEIC ACID.

Nucleic acid has been found to be a constituent part of the soil organic matter in the course of the investigations carried on in this laboratory. When it occurs it forms a constituent part of the so-called humus, precipitated by the addition of acid to an alkaline extract of soils. Its method of separation and identification is described in Bulletin No. 88 of this Bureau.

Nucleic acid is a common constituent of all plant and animal material and its source in the soil is doubtless due to its accumulation from vegetable and animal débris and from the bodies of the microorganisms of the soil—the bacteria, the molds, the protozoa, etc. Chemically it is a complex substance, capable of being split into much simpler units, such as phosphoric acid on the one hand, and nitrogenous compounds on the other, such as the purine and pyrimidine compounds, hypoxanthine, xanthine, adenine, guanine, and cytosine, all of which have been found in soils in the course of these investigations, as well as carbohydrate units, such as pentose sugars, likewise found in soils. In addition to these ultimate units of degradation, there exist the intermediate combinations such as a (pentose sugar)-(purine base) complex and other combinations of the above constituent parts. The exact chemical constitution of the nucleic acids is not known, but these derivatives of it are well identified. These chemical characteristics will be discussed more fully in connection with another subject in Bulletin 89.

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[1] Jour. Am. Chem. Soc., 25, 1063 (1903).

For the purpose of these cultural tests, requiring appreciable quantities of nucleic acid, the compound prepared from yeast was used. This yeast nucleic acid was dissolved in water and used in making up the cultures. In order to counteract the acidity, calcium carbonate was added to each nucleic acid culture and also to each culture in the control set for the purpose of better comparison. Both sets of cultures grew, therefore, under the slightly physiologically alkaline conditions imposed by the calcium carbonate.

Two sets of cultures composed of the fertilizer salts, calcium acid phosphate, sodium nitrate, and potassium sulphate, in varying proportions, used singly and in combinations of two and three, were prepared according to the method already described. To one set of cultures only the nutrient salts were added, to the second set 100 parts per million of the nucleic acid were added to each culture solution. Wheat seedlings were grown in both sets of culture solutions from April 8 to April 21, 1911. Every three days the solutions were changed and the nitrates determined.

When the two sets of cultures had grown in the greenhouse under identical conditions for several days the effect of the nucleic acid was already noticeable by a superior growth in the nucleic acid cultures, an effect which became quite marked as the experiment progressed. This was more marked in some of the fertilizer combinations than in others, but consistently so, as will be shown. Direct comparison between the two sets showed the effect of nucleic acid in producing increased growth to be most pronounced in those fertilizers which contained no nitrate and in those low in nitrate.

At the end of the experiment the green weight of the tops of both sets was taken and the results obtained will be found in the following tables. The total growth in the 66 cultures of nutrient salts without nucleic acid, designated as normal or control cultures, was 163.3

grams, against 200.7 grams in the case of the 66 cultures with 100 parts per million of nucleic acid. Putting the normal at 100, the latter becomes 122, or an increase of 22 per cent in green weight, as an average of the 66 cultures, although as mentioned already, and as will be shown further on, this increase is more marked in those cultures low in nitrate than in those high in nitrate.

GROWTH IN CULTURES CONTAINING NO NITRATE.

Table III gives the growth of the two sets of cultures comprising the line of cultures containing no nitrate, but containing mixtures of potash and phosphate, varying in 10 per cent stages, the total concentration being 80 parts per million of $P_2O_5+K_2O$ in each culture. In the fifth column are given the weights of the cultures without nucleic acid, and in the last column the weights of the cultures where nucleic acid was present. It is apparent from these figures that the nucleic acid has caused a considerable increase in growth. This is true in each of the eleven cultures. For instance, in culture No. 37 which has 16 parts per million of phosphate and 64 parts per million of potash, the growth without nucleic acid is 1.870 grams, and with nucleic acid 3.520 grams. Culture No. 16, which is composed of equal parts of phosphate and potash, produced 1.490 grams green weight when nucleic acid was absent and 3.440 grams when the nucleic acid was present in the solution. The growth in culture No. 4, which is composed of 64 parts per million of phosphate and 16 parts per million of potash, was 1.378 grams without nucleic acid and 2.528 grams with nucleic acid.

TABLE III.—*Effect of nucleic acid on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without nucleic acid.	With 100 p. p. m. nucleic acid.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.599	3.090
46	8	0	72	1.770	3.040
37	16	0	64	1.870	3.520
29	24	0	56	1.859	3.100
22	32	0	48	1.578	3.000
16	40	0	40	1.490	3.440
11	48	0	32	1.890	2.750
7	56	0	24	1.520	2.800
4	64	0	16	1.378	2.528
2	72	0	8	1.428	1.859
1	80	0	0	0.859	0.970

The total green weight of the 11 cultures without nucleic acid, composed of mixtures of phosphate and potash only, was 17.241 grams, against 30.097 grams for the cultures with nucleic acid. This is an increase of 74 per cent produced by the addition of nucleic acid to the line of cultures containing no nitrate.

The results here recorded on the green weight are in full accord with the actual observations made on the plants while growing, as was mentioned earlier. For the purpose of record, a photograph of this line of cultures was taken after arranging the two sets, with and without nucleic acid, alternately, in pairs of like composition in regard to the mineral salts, phosphate and potash. This photograph is reproduced in Plate II.

Cultures marked with the same number, for instance 56 and 56*N*, have similar fertilizer ratios. The cultures marked with numbers alone have no nucleic acid, those with numbers and the letter *N* have 100 parts per million of nucleic acid. The composition of the respective cultures is given in Table III.

As shown in Plate II, the plants in each culture containing nucleic acid, no matter what the proportion of potash and phosphate, are larger than the plants growing in a similar solution without the nucleic acid, the tops in each case being broader and taller.

NUCLEIC ACID IN CULTURES CONTAINING 8 PARTS PER MILLION NH_3 AS NITRATE.

Since nucleic acid was very beneficial in cultures containing no nitrate, it is interesting to observe its effect in cultures which contain a small amount of nitrate, as is the case in the next line of cultures. Nos. 3 to 57, Table IV, gives the result of the effect of nucleic acid on growth in these culture solutions composed of 8 parts per million of NH_3 as nitrate and varying amounts of potash and phosphate, the total concentration of each solution being 80 parts per million of $P_2O_5+NH_3+K_2O$. By comparing the figures in the fifth and sixth columns, it is seen that the growth with nucleic acid is still considerable larger, but the difference caused by the nucleic acid is not near so great as in solutions containing no nitrate, presented in Table III. The total green weight of these 10 cultures was, without nucleic acid, 25.272 grams, against 31.080 grams in the cultures with nucleic acid, an increase of 23 per cent. In the cultures with no nitrate the nucleic acid produced an increase of 74 per cent.

TABLE IV.—*Effect of nucleic acid on growth in culture solutions containing 8 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without nucleic acid.	With 100 p. p. m. nucleic acid.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	2.709	3.400
47	8	8	64	2.590	3.340
38	16	8	56	2.890	3.300
30	24	8	48	2.629	3.700
23	32	8	40	2.850	3.700
17	40	8	32	2.770	3.600
12	48	8	24	2.800	3.150
8	56	8	16	2.200	2.750
5	64	8	8	2.225	2.500
3	72	8	0	1.609	1.640

NUCLEIC ACID IN CULTURES WITH LARGER AMOUNTS OF NITRATE.

The third line of cultures containing 16 parts per million of NH_3 as nitrate did not produce as much additional growth when nucleic acid was added as did the two series with no nitrate, and with 8 parts per million of nitrate, just discussed. This is shown by the results in Table V. The total green weight of the cultures without the nucleic acid was 26.483 grams, against 29.730 grams for the nucleic acid cultures, an increase of 12 per cent.

TABLE V.—*Effect of nucleic acid on growth in culture solutions containing 16 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without nucleic acid.	With 100 p.p.m. nucleic acid.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
58	0	16	64	2.900	3.800
48	8	16	56	3.500	4.300
39	16	16	48	3.150	3.450
31	24	16	40	3.300	3.770
24	32	16	32	3.249	3.700
18	40	16	24	3.439	3.550
13	48	16	16	2.800	3.190
9	56	16	8	2.400	2.320
6	64	16	0	1.745	1.650

In the remaining cultures of the triangle the effect of the nucleic acid was noticeable, but there was on the whole no effect greater than that already noted in the case of the cultures with 16 parts per million of NH_3 as nitrate. The series of cultures containing 24 parts per million NH_3 as nitrate showed an increase of 11 per cent on the addition of nucleic acid; the 32 parts per million series showed an increase of 13 per cent; the 40 parts per million, 14 per cent; the 48 parts per million, 15 per cent; the 56 parts per million, 7 per cent; the 64 parts per million, 20 per cent; the 72 parts per million, 10 per cent; the 80 parts per million, no increase. The last is represented only by a single culture which showed, in fact, a slight decrease.

ABSORPTION OF NITRATE IN THE PRESENCE OF NUCLEIC ACID.

It is apparent from the foregoing that nucleic acid is beneficial to growth and that its effect is most marked in nitrate free solutions, showing that it can take the place of nitrates in producing growth. With increasing nitrate content the effect of nucleic acid in increasing growth, beyond that produced by the nutrient salts, becomes less, but is nevertheless appreciable. That it still plays a part in taking the place of nitrate in producing growth, even in the solutions which contain nitrate, is shown by the result obtained in analytically determining the removal of nitrate from the culture solutions during growth. The culture solutions were changed every three days, as already mentioned, and the amount of nitrate remaining in the solution determined. In this way it was found that in the 55 cultures containing nitrate, but no nucleic acid, the amount of nitrate removed was 666.8 milligrams, whereas the amount of nitrate removed in the presence of nucleic acid was only 516.1 milligrams, thus showing a greatly diminished nitrate requirement, only 77 per cent of the control, when nucleic acid is furnished the plant, although a much greater growth, over 20 per cent increase, has resulted.

HYPOXANTHINE.

Hypoxanthine has been isolated from a number of soils, having been found in 9 out of 24 soils examined for it. It appears, therefore, to be a soil constituent which will be frequently encountered in soil investigations. Hypoxanthine exists in some plants as such, but probably arises principally in the soil as a result of the cleavage of nucleic acids and nucleo-proteids. Its occurrence among the splitting products of nucleic acid has already been mentioned when the latter compound was under discussion. In the light of the beneficial effect of the nucleic acid, it is especially interesting to know the effect which this rather definite soil constituent, which, as mentioned above, can be considered as a product resulting from nucleic acid, has upon plants.

In testing the effect of hypoxanthine on wheat seedlings, the experiment procedure was similar to that described under the heading nucleic acid. Two sets of the 66 nutrient cultures were prepared, the one having added to each culture 100 parts per million of hypoxanthine, the other set being used as a control. The seedlings grew from February 1 to February 13, 1911. The solutions were changed every three days. In the case of hypoxanthine, in addition to the determination of the nitrate immediately after making the change of solutions in the cultures, the phosphate and potash were determined in a composite of the four changes in each culture. Only the cultures containing all these fertilizer elements were thus analyzed. It was apparent almost from the start that the hypoxanthine set of cultures was making better growth than the set not containing this substance. The plants were better developed, had broader leaves and longer and better developed roots. These effects were especially noticeable in the cultures containing no nitrate when these were compared with the same cultures in the control set.

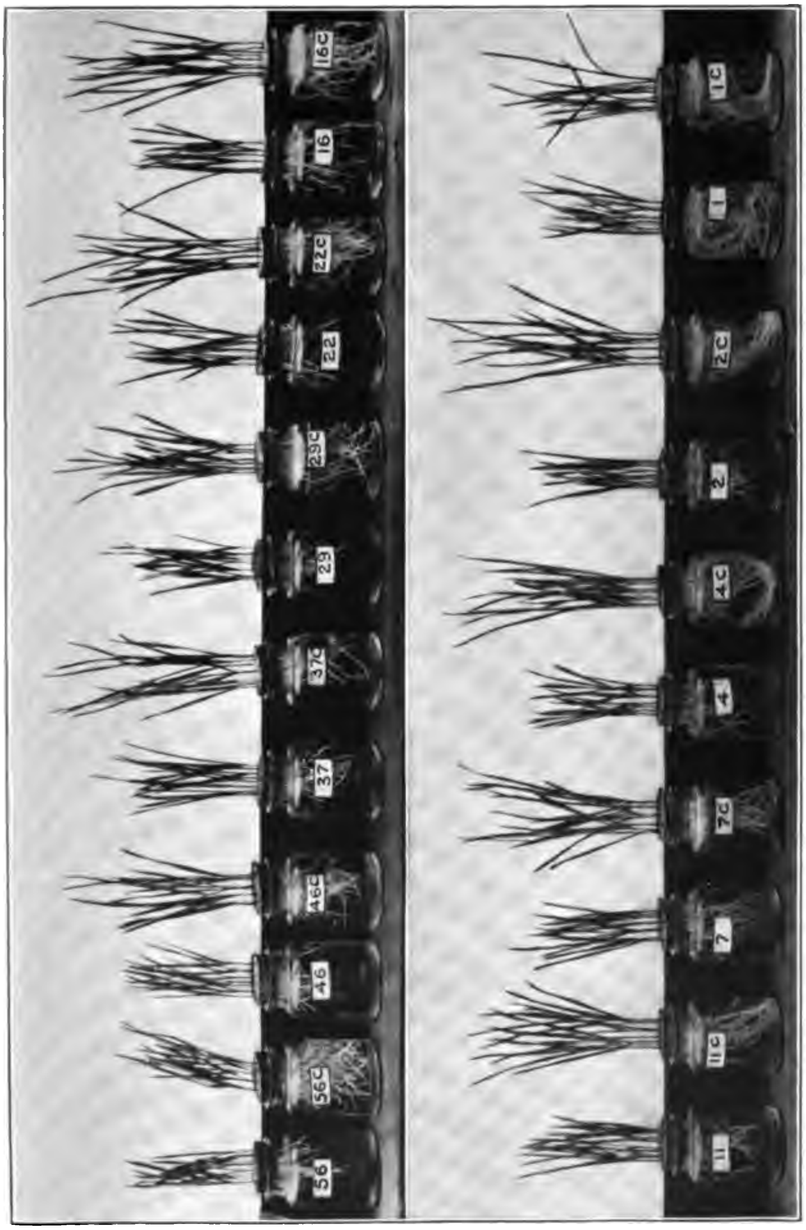
The green weight of the cultures was taken at the termination of the experiment. The total weight of the 66 normal or control cultures was 139.4 grams against 150.1 grams for the 66 cultures with the hypoxanthine. With the normal at 100 the hypoxanthine cultures become 108, or an average increase of 8 per cent for all the cultures. The effect, however, was most marked in those cultures in which nitrate was absent or low as will now be shown.

GROWTH IN CULTURES CONTAINING NO NITRATE.

Table VI gives the growth of the line of cultures in both sets, with and without hypoxanthine, which contained no nitrate. In every case, the comparison of the last two columns of the table shows an increase in the hypoxanthine culture, although this naturally varies with the different combinations of phosphate and potash in these cultures. The total green weight of the series without hypoxanthine is 14.220 grams, against 20.015 grams in the hypoxanthine cultures, or an average increase of 41 per cent.

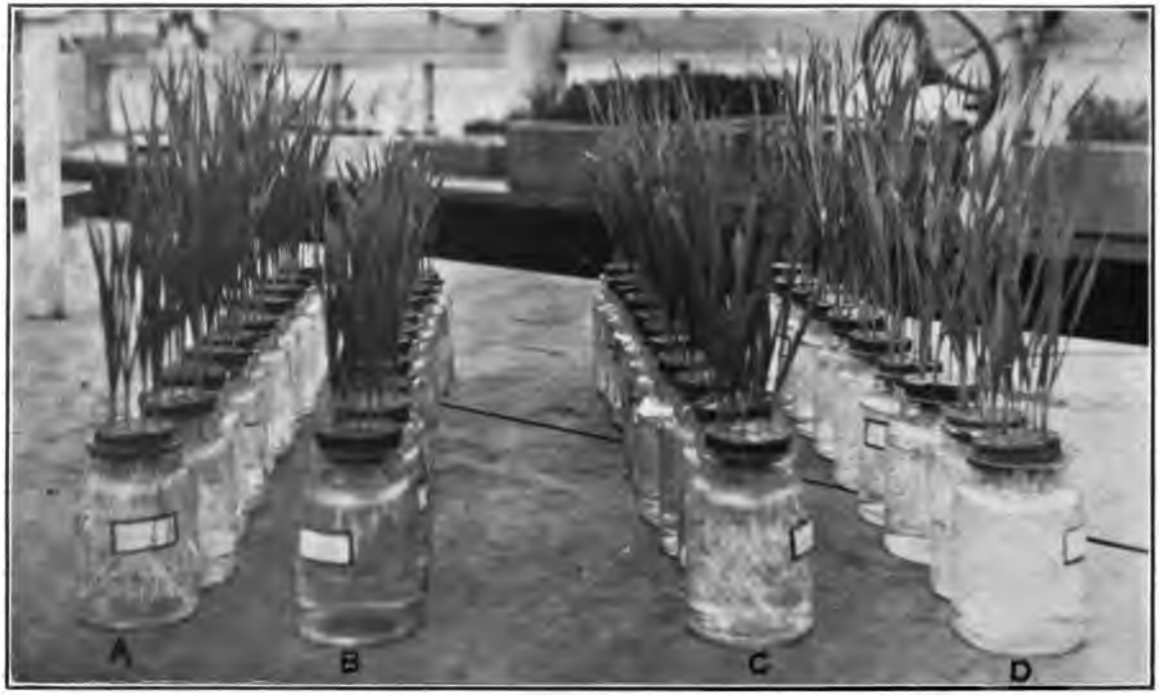
TABLE VI.—*Effect of hypoxanthine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without hypoxanthine.	With 100 p. p. m. hypoxanthine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.178	1.370
46	8	0	72	1.390	2.190
37	16	0	64	1.320	1.628
29	24	0	56	1.250	2.059
22	32	0	48	1.309	2.220
16	40	0	40	1.320	2.100
11	48	0	32	1.300	2.198
7	56	0	24	1.465	1.820
4	64	0	16	1.498	1.720
2	72	0	8	1.190	1.655
1	80	0	0	1.000	1.055



BENEFICIAL EFFECT OF CREATININE, AN ORGANIC SOIL CONSTITUENT, IN CULTURE SOLUTIONS OF DIFFERENT COMPOSITION.

[Cultures marked C contain creatinine.]



WHEAT PLANTS GROWING IN CULTURE SOLUTIONS, WITH AND WITHOUT CREATININE, CONTAINING NO NITRATE, AND 8 PARTS PER MILLION OF NH_3 AS NITRATE.

[Series A: Culture solutions, composed of a fertilizer mixture containing 8 parts per million NH_3 as nitrate. Series B: Culture solutions, composed of a fertilizer mixture containing no nitrate, without creatinine. Series C: Culture solutions, composed of a fertilizer mixture containing no nitrate, with creatinine. Series D: Culture solutions, composed of a fertilizer mixture containing 8 parts per million of nitrate, with creatinine.]

HYPOXANTHINE IN CULTURES CONTAINING 8 PARTS PER MILLION NH_3 AS NITRATE.

Table VII shows the effect which hypoxanthine had when added to culture solutions which already contained a small amount of nitrate. This is the series of cultures in the second line of the triangle, that is, those containing uniformly 8 parts per million of NH_3 as nitrate, but varying amounts of phosphate and potash as is shown in Table VII. The comparison of the last two columns shows that the hypoxanthine cultures are heavier in each case, but the difference is not nearly so great as in Table VI. The total green weight in the series of cultures without hypoxanthine is 20.707 grams and with hypoxanthine it is 23.672 grams, an average increase of 14 per cent, as against the 41 per cent shown by cultures given in Table VI.

TABLE VII.—*Effect of hypoxanthine on growth in culture solutions containing 8 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without hypoxanthine.	With 100 p. p. m. hypoxanthine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	1.748	2.150
47	8	8	64	2.440	2.772
38	16	8	56	2.150	2.470
30	24	8	48	2.000	2.628
23	32	8	40	2.390	2.692
17	40	8	32	2.456	2.850
12	48	8	24	2.370	2.640
8	56	8	16	2.275	2.450
5	64	8	8	1.800	1.920
3	72	8	0	1.078	1.100

HYPOXANTHINE IN CULTURES WITH LARGER AMOUNTS OF NITRATES.

When the effect of the hypoxanthine in the series of cultures containing 16 parts per million of NH_3 as nitrate is considered, it is found that the effect is still less marked than either of the above results. This is shown in Table VIII, where the growth with hypoxanthine, while still greater than the growth without this ingredient, is nevertheless not so clearly marked as in the two series of cultures already considered. The average increase in these 16 parts per million of NH_3 as nitrate cultures occasioned by the hypoxanthine is only 3 per cent, while the 8 parts per million nitrate series was 14 per cent and the no nitrate series was 41 per cent.

TABLE VIII.—*Effect of hypoxanthine on growth in culture solutions containing 16 p. p. m. of* NH_3 *as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without hypoxanthine.	With 100 p. p. m. hypoxanthine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
58	0	16	64	2.120	2.224
48	8	16	56	2.800	2.500
39	16	16	48	2.750	2.900
31	24	16	40	2.722	3.059
24	32	16	32	2.770	3.094
18	40	16	24	2.926	3.000
13	48	16	16	2.490	2.500
9	56	16	8	1.974	2.100
5	64	16	0	1.270	1.150

With still larger amounts of nitrate present the additional effect was less certain. In some cases the hypoxanthine produced an increase in growth, in others a slight decrease, so that the result in the two sets of cultures with these higher nitrate contents was practically alike. In other words, no additional effect caused by the addition of the hypoxanthine is definitely shown on the green weight, but an effect was produced, nevertheless, in that less nitrate was consumed while this equal growth took place, as will be shown.

INFLUENCE OF HYPOXANTHINE ON ABSORPTION OF FERTILIZER SALTS.

The foregoing discussion has shown clearly the influence of hypoxanthine on growth and its effect in cultures containing no nitrate. There remains to be discussed the effect of hypoxanthine on the removal of nutrients from the solution during the growth of the plant. Mention has already been made of the fact that the concentration differences produced by the growth of the plants in the various cultures was determined by making an analysis for nitrate at the termination of every three-day change, and of the phosphate and potassium on a composite of the solutions from the four changes. It is thus possible to compare the results obtained under the control condition without the hypoxanthine and under the condition where 100 parts per million of hypoxanthine were present in the solution.

The sum total of P_2O_5, NH_3, and K_2O removed from solution by the growing plants in the cultures containing all three of these constituents was 1,429.1 milligrams under the normal conditions and 1,134.2 milligrams in the hypoxanthine set. The figures show the total of plant nutrients removed to be less in the hypoxanthine set, although the green weight in this set was greater than in the normal set. When the removal of the individual fertilizer elements, NH_3, P_2O_5, and K_2O, respectively, from the culture solutions is considered, it is found that in the presence of hypoxanthine the nitrate is greatly conserved; that is, much less nitrate is consumed by the plant in the presence of hypoxanthine.

The quantity of phosphate removed from the solutions of the normal set was 330.1 milligrams and from the hypoxanthine set 361.2, indicating a slightly greater phosphate requirement by the larger plants.

The quantity of potash removed from the solutions of the normal set was 603.1 milligrams and from the hypoxanthine set 521.1 milligrams, indicating a somewhat decreased potash absorption amounting to 82 milligrams.

The quantity of nitrate consumed in the normal cultures was 450.1 milligrams and in the hypoxanthine cultures only 247.6 milligrams. This shows a decreased consumption of nitrates amounting to 202.5 milligrams by the cultures growing in the presence of hypoxanthine, although, as shown above, an increased growth took place. It is obvious that the hypoxanthine is able to replace the effect of nitrate in producing growth.

XANTHINE.

Xanthine, closely related to hypoxanthine, has likewise been isolated and identified as a soil constituent. While it has not been found as often as hypoxanthine, it appears nevertheless to be a frequent constituent of soils and in several cases has been identified in the same soils in which hypoxanthine occurred.

Xanthine occurs as such in a number of plants, as well as in animal substances. It has been found in yellow lupines, sprouts of malt, sprouts of lupines, *Vicia sativa*, *Cucurbita*, *Phaseolus*, and tea leaves and no doubt further investigation will disclose its presence in many other plants. While it may get into the soil from these sources, it is more probable that the most constant source of this soil constituent, like the other purine bases, is in the decomposition of nucleic acids and nucleoproteins in the soil.

While xanthine has not been as thoroughly studied as the hypoxanthine in respect to its effect on plant growth, the results obtained with this compound point, however, in the same direction, and show that xanthine is beneficial to plants. The effect of xanthine in connection with fertilizer salts has not been studied as this earlier work was done before the more extended method with fertilizer salts was worked out. The xanthine is not very soluble in water but a solution of 25 parts per million when compared with a control culture in pure distilled water showed an increase in green weight equal to 21 per cent, which is clearly in harmony with the beneficial effects of hypoxanthine more fully studied.

GUANINE.

Guanine, the other common purine base resulting from the breaking down of nucleoproteins and nucleic acids, has also been found in soil in connection with investigations in this laboratory which will be reported in Bulletin 89. It is a constituent of guano and has been found as a product of the autolysis of yeast. It appears to be rather widely distributed and has been found in the seeds of vetch, alfalfa, clover, and gourd, in germinating barley, in sugar beet, and in sugar cane.

Guanine, like xanthine, was tested in distilled water solutions only, and owing to its slight solubility a concentration greater than 40 parts per million could not be tested. In this concentration the increase in growth noticed was 5 per cent over that of the growth in a distilled-water control. The root development was especially marked, long, white, and clean roots being obtained, which were very healthy in appearance. The result indicates that guanine should be classed as a compound beneficial to growth.

ADENINE.

Adenine also has been found as a soil constituent, as will be reported later, and its source in the soil is probably the same as those of the other purine compounds, guanine, xanthine, and hypoxanthine, already discussed, but we have not had sufficient material in hand, either from soil or other source, to make any study of its effect on plants.

CREATININE.

In the course of investigations into the nature of soil organic matter a crystalline organic compound was isolated and identified as creatinine. Since then it has been found in a number of soils of widely different type and from widely separated areas, and is apparently a common soil constituent. The actual quantity, while not large, is nevertheless appreciable and about as great as is the store of nitrate in ordinary soils, and it is not improbable that the quantity of creatinine is a fluctuating quantity as is the nitrate.

It has been obtained from soils by chemical methods and also by extraction with alcohol and even with water. Creatinine has been considered as a product of animal origin, but in the investigations of this laboratory it has also been found as a constituent of vegetable material. It was found in wheat seeds, wheat seedlings, wheat bran, rye, clover, alfalfa, cowpeas, and potatoes. Its occurrence in these plants, some of which are used for purposes of green manuring, as well as its occurrence in stable manure, may partially explain its presence in soils, but it may possibly also arise during the decay of more complex protein bodies and nucleic acids or be produced by the action of bacteria and molds.

Guanidine and arginine are structurally related to creatinine. Of these, arginine has already been found in soils, but only infrequently and in small quantities. Guanidine, although it has been found in plants, has not yet been isolated from a soil, but the purine base, guanine, which has been found in soil under certain conditions, is capable of yielding guanidine on oxidation. This possible connection of creatinine with the purine bases and the nucleic acids, the action of which on plant growth has already been presented, is, in the present state of knowledge, however, purely speculative.

In studying the effect of creatinine on crops, wheat seedlings were grown in aqueous culture solutions containing the ordinary fertilizer salts, calcium acid phosphate, sodium nitrate, and potassium sulphate, the details being in every respect the same as in the experiments with hypoxanthine already described.

Two sets of cultures were prepared and young wheat seedlings were grown in them from March 3 to March 15, 1911. To one set of cultures only the nutrient salts were added, to the second set 50 parts per million of creatinine were added to each culture. Every three days the solutions were changed and analyzed. The solutions were analyzed for nitrates immediately after each change. The phosphate and potassium were determined on a composite solution of the four changes. Observations on the development of the plants were made during the experiment and photographs were taken. At the termination of the experiment the green weight was taken and recorded.

When the plants had grown for several days it was noticeable that the creatinine cultures were better developed, having broader leaves and longer and better developed roots. The total growth made in the 66 cultures of nutrient salts without creatinine, designated as normal or control cultures, was 166.7 grams, as against 181.2 grams in the case of the 66 cultures with 50 parts per million of creatinine. Putting the normal at 100, the latter becomes 109, or an increase of 9 per cent, as an average of the 66 cultures. The effect was much more pronounced in those fertilizer combinations containing no nitrate and those low in nitrate as was the case with the hypoxanthine and the nucleic acid.

GROWTH IN CULTURES CONTAINING NO NITRATE, WITH AND WITHOUT CREATININE.

Table IX gives the growth of the two sets of cultures which contained no nitrate in the solutions, the cultures and the arrangement being the same as in Tables III and VI. To one set of cultures had been added 50 parts per million of creatinine. In the fifth column are given the green weights of the cultures without creatinine, and in the last column are given the weights of the cultures with creatinine. It is apparent from these figures that the creatinine has caused a considerable increase in growth. This is true in each of the 11 cultures. The total growth of the 11 cultures, without creatinine, composed of mixtures of phosphate and potash, was 16.674 grams, against 22.682 grams for the cultures with creatinine. This is an increase of 36 per cent in the creatinine cultures.

TABLE IX.—*Effect of creatinine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without creatinine.	With 50 p. p. m. creatinine.
	P.p.m.	*P.p.m.*	*P.p.m.*	*Grams.*	*Grams.*
56	0	0	80	1.400	1.576
46	8	0	72	1.470	2.200
37	16	0	64	1.950	2.100
29	24	0	56	1.527	2.000
22	32	0	48	1.490	2.200
16	40	0	40	1.558	2.408
11	48	0	32	1.795	2.328
7	56	0	24	1.540	2.400
4	64	0	16	1.444	2.220
2	72	0	8	1.400	2.100
1	80	0	0	1.100	1.150

The effect of creatinine in cultures with no nitrate is shown in Plate III. Cultures marked with the same number, for instance 1 and 1*C*, have similar fertilizer ratios. The cultures marked with numbers alone have no creatinine. The compositions of the culture solutions correspond with those given in Table IX.

As shown in Plate III, the plants in each culture containing creatinine, no matter what the proportion of potash and phosphate, are larger than the plants grown in a similar solution without the creatinine. The increased growth is noticeable in the roots as well as in the tops. The blades in each case are broader and taller and the roots are larger and better branches.

CREATININE IN CULTURES CONTAINING 8 PARTS PER MILLION NH_3 AS NITRATE.

Since creatinine was very beneficial in cultures containing no nitrate it is interesting to observe its effect in cultures that contain a small amount of nitrate. Table X gives the result of the effect of creatinine on growth in culture solutions containing 8 parts per million NH_3 as nitrate. By comparing the figures in the last two columns it is seen that the growth with creatinine, given in the last column, is larger than the growth without creatinine, given in the fifth column. The difference, however, is not nearly so great as in solutions containing no nitrate, presented in Table IX. The total green weight of the cultures without creatinine was 24.071 grams against 28.117 grams in the cultures with creatinine, an increase of 17 per cent. In the cultures with no nitrate creatinine produced an increase of 36 per cent.

TABLE X.—*Effect of creatinine on growth in culture solutions composed of fertilizer mixtures, containing 8 parts per million of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without creatinine.	With 50 p. p. m. creatinine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	1.820	2.190
47	8	8	64	2.470	3.100
38	16	8	56	2.748	3.250
30	24	8	48	2.907	3.420
23	32	8	40	2.670	2.450
17	40	8	32	2.928	3.258
12	48	8	24	2.526	3.340
8	56	8	16	2.600	3.000
5	64	8	8	2.048	2.359
3	72	8	0	1.354	1.750

In Table XI are given the results of growth in culture solutions with and without creatinine, composed of mixtures of phosphate, potash, and nitrate. The proportions of phosphate and potash vary in the different cultures, but each solution has 16 parts per million of NH_3 as nitrate. The green weights of the creatinine cultures, given in the last column of the table, are slightly larger than the control cultures shown in the fifth column. The total green weight of the cultures without creatinine was 25.516 grams against 27.573 grams for the cultures with creatinine, an increase of 8 per cent.

TABLE XI.—*Effect of creatinine in culture solutions containing 16 parts per million of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without creatinine.	With 50 p. p. m creatinine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
58	0	16	64	2.200	2.570
48	8	16	56	3.200	3.720
39	16	16	48	3.400	3.500
31	24	16	40	3.097	3.702
24	32	16	32	3.250	3.250
18	40	16	24	3.228	3.300
13	48	16	16	2.975	3.240
9	56	16	8	2.626	2.551
6	64	16	0	1.440	1.740

In the series of cultures containing 24 parts per million NH_3 as nitrate, creatinine only increased growth 2 per cent. Its effect in cultures composed of fertilizer mixtures having more than 24 parts per million of NH_3 as nitrate was uncertain. In some cases there was a slight increase in growth and in others there was a slight decrease. However, in all cases with large amounts of nitrate the growth was practically the same in the normal and creatinine cultures.

Plate IV shows the effect of creatinine with and without nitrate. As seen in the photograph there is a large difference between the control cultures having a small amount of nitrate (series A) and those without nitrate (series B). The no-nitrate plants have small tops and poorly developed roots, while the nitrate plants have large tops and well-branched roots. Series C, creatinine cultures without nitrate, compared with series D, creatinine cultures with nitrate, shows that this difference is not so great as in the case of the normal cultures with and without nitrate.

The effect of creatinine in cultures containing no nitrate is well shown by comparing series B with series C: Series A compared with series D shows that creatinine does not produce so great an additional effect when nitrogen as nitrate is in the culture.

INFLUENCE OF CREATININE ON ABSORPTION OF FERTILIZER SALTS.

The foregoing discussion has shown clearly the influence of creatinine on growth and its effect in cultures containing no nitrate. There remains to be discussed the effect of the creatinine on the removal of nutrients from the solution during the growth of the plant.

The concentration differences produced by the growth of the plants in the various cultures was determined by making an analysis for nitrate at the termination of every three-day change, and of the phosphate and potassium on a composite of the solutions from the four changes. It is thus possible to compare the results obtained under the control conditions without the creatinine and under the conditions where 50 parts per million of the creatinine were present in the solution.

The sum total of P_2O_5, NH_3, and K_2O removed from the solution by the growing plants in the cultures containing all three of these constituents was 1,684 milligrams under the control conditions and 1,584 milligrams in the creatinine set. The figures show the total of plant nutrients removed to be slightly less in the creatinine set, although the green weight in this set was greater than in the normal set. The examination of the results for the three constituents separately as given below, shows that the phosphate and potash absorption were slightly greater than normal, as is demanded by the larger growth, whereas the nitrate removal is considerably less than in the normal set.

The amount of phosphate removed was 364 milligrams for the normal cultures and 383 milligrams for the cultures containing creatinine, a difference of 19 milligrams in favor of the creatinine cultures.

The amount of potash removed by the plants was 760 milligrams in the case of the normal cultures and 778 milligrams for the cultures with creatinine. As with the phosphate, the creatinine cultures removed a little more potash than the normal cultures, there being a difference of 18 milligrams in favor of the creatinine set.

The total amount of nitrate, stated as NH_3, removed from the solutions during the course of the experiment was 560 milligrams for the normal cultures and 423 milligrams for the creatinine cultures. The creatinine cultures, although making a larger growth, used 137 milligrams less nitrate.

The result of tests for the possible formation of nitrate, nitrite, ammonia, or creatine have been discussed in the earlier sections of this bulletin.

CREATINE.

Creatine and the creatinine discussed in the preceding section, are so closely related that the determination of one of these in a soil makes the occurrence of the other highly probable. Both probably occur in soils, manures, and green crops. Creatinine is the anhydride of creatine, and is readily formed in the laboratory from creatine by heating with acids or by heating the crystallized creatine under pressure.

Experiments in nutrient cultures with creatine have been conducted similar to those with creatinine. The plants grew from April 22 to May 4, 1911. After the plants had grown for several days, it was apparent that the effect of creatine was very similar to that of creatinine. The leaves were broader and further developed than the control cultures. The roots were longer and better branched. The plants growing in creatine cultures which contained phosphate and potash, but no nitrate, were a great deal larger than similar cultures without creatine. Like the creatinine, when a small amount of nitrate was in the fertilizer mixture the beneficial effect of creatine was not so marked, and in the presence of a larger amount of nitrate creatine had no additional effect on growth.

The total green weight of 66 cultures containing the fertilizer salts only, that is, the control set, was 174.4 grams, against 186.8 grams for the 66 cultures containing 50 parts per million of creatine in addition to the fertilizer salts. This is an average increase for the creatine cultures of 8 per cent over the control cultures.

Table XII shows the effect of creatine on growth in the series of cultures containing varying quantities of phosphate and potash, but no nitrate. From an examination of the table, it is apparent that the growth of each of the creatine cultures, given in the last column, is considerably larger than the growth of the cultures without creatine, given in the fifth column. The total green weight of the cultures without creatine was 16.2 grams, against 23.2 grams for the cultures with creatine, an increase of 44 per cent.

TABLE XII.—*Effect of creatine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without creatine.	With 50 p. p. m. creatine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.329	1.709
46	8	0	72	1.420	1.948
37	16	0	64	1.558	2.130
29	24	0	56	1.579	2.370
22	32	0	48	1.528	2.470
16	40	0	40	1.500	2.400
11	48	0	32	1.670	2.270
7	56	0	24	1.628	2.420
4	64	0	16	1.600	2.450
2	72	0	8	1.428	2.070
1	80	0	0	.978	1.090

In Table XIII are given the green weights of plants grown in cultures with and without creatine, containing 8 parts per million of NH_3 as nitrate and varying amounts of phosphate and potash. These figures show that the creatine cultures, given in the last column, are somewhat larger than the cultures without creatine, given in the fifth column, but the difference is not nearly so great as in the cultures containing no nitrate given in Table XII. The total growth of the cultures without creatine was 26.4 grams, against 29.4 grams for the cultures with creatine, an increase of only 11 per cent in favor of the creatine cultures. There was a difference of 44 per cent in favor of the creatine cultures in the case of the solutions which contained no nitrate.

TABLE XIII.—*Effect of creatine on growth in culture solutions containing 8 parts per million of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without creatine.	With 50 p. p. m. creatine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	2.299	2.459
47	8	8	64	2.940	3.200
38	16	8	56	2.700	3.350
30	24	8	48	2.920	3.400
23	32	8	40	3.050	3.070
17	40	8	32	3.150	3.309
12	48	8	24	3.220	3.350
8	56	8	16	2.500	2.854
5	64	8	8	2.222	2.800
3	72	8	0	1.400	1.600

The growth in the series of cultures which contained 16 parts per million of NH_3 as nitrate was only 3 per cent greater with creatine than without creatine. The growth in this series of cultures is given in Table XIV. In solutions containing 24 parts per million of NH_3 as nitrate the increased growth with creatine was 6 per cent, and in solutions containing 32 parts per million NH_3 as nitrate the increased growth was 4 per cent. In solutions containing higher amounts of nitrate the creatine had no additional effect. Thus it appears that the effect of creatine in replacing the effect of nitrate in producing growth is very similar to that of creatinine.

TABLE XIV.—*Effect of creatine on growth in culture solutions containing 16 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without creatine.	With 50 p. p. m. creatine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
58	0	16	64	2.890	2.508
48	8	16	56	3.420	3.570
39	16	16	48	3.420	3.770
31	24	16	40	3.900	4.050
24	32	16	32	3.820	3.970
18	40	16	24	3.600	3.729
13	48	16	16	2.700	3.150
9	56	16	8	2.858	2.476
6	64	16	0	1.528	1.740

It is also interesting to note the effect of creatine on the removal of salts by the plants, and the similarity between the action of creatine and creatinine in this respect. It will be remembered that in the creatinine cultures the removal of phosphate and potash was slightly greater in the creatinine cultures than in the control cultures, but a great deal less nitrate was consumed in the creatinine than in the control cultures.

In the creatine experiment the removal of total P_2O_5, NH_3, and K_2O by plants in the control cultures was 1,978.3 milligrams, against 1,854.5 milligrams for the creatine cultures. The control cultures removed 471.0 milligrams of phosphate, and the creatine cultures 474.4 milligrams. In the case of potash the control cultures removed 769.4 milligrams of K_2O, against 767.4 milligrams for the creatine cultures. The removal of both phosphate and potash was practically the same in the control and creatine cultures. The nitrate removal was much less in the creatine than in the control cultures. The control cultures consumed 737.7 milligrams, against 612.7 milligrams for the creatine cultures, a difference of 125 milligrams.

The influence of the creatine as regards the removal of phosphate, nitrate, and potash is very similar to that shown by creatinine, and it again appears that this substance as well as the creatinine can replace nitrate in its effects on plant growth.

HISTIDINE.

Histidine is a primary decomposition product of protein material and has been found in soils. All protein bodies give some diamino acids or hexone bases on decomposition, the proportion and kind of degradation product varying in the different proteins. Histidine is one of those most frequently encountered as a degradation product of proteins. Likewise it has been found quite frequently in soils.

Its occurrence in 17 out of 24 soils examined for it indicates that this hexone base is a fairly common constituent of soils and shows, therefore, that the protein change in soil is similar to that brought about by chemical or other action in laboratory investigations.

The histidine, as usually prepared, is in the form of the characteristic dihydrochloride, which crystallizes nicely in glassy plates or prisms. This salt, however, hydrolyses readily, so that its solutions are rather acid in reaction. For the purpose of this cultural work the pure dihydrochloride was, therefore, changed over to the carbonate.

Two sets of culture solutions were again prepared as in the experiments already described, except that, owing to a limited supply of the histidine carbonate, the extent of the cultures used was confined to the four series; those containing no nitrate and 8, 16 and 24 parts per million of NH_3 as nitrate, respectively. That is, the cultures higher than this amount of nitrate were omitted in the light of the results obtained with these higher cultures in the case of the related compounds already studied. The cultures omitted from the general scheme, shown in figure 1, are those contained in the subtriangle 15–60–66, all other cultures being used in the experiment, a total of 38. To one set of the cultures only the nutrient salts were added, to the other set, in addition to the nutrient salts, 50 parts per million of histidine carbonate were added to each culture. As before, the culture solutions were changed every three days and analyzed. The cultures grew from November 15 to November 27, 1911.

After the two sets of plants had grown for a few days, with and without the histidine, it was quite apparent that the histidine had the same effect in promoting plant growth as had the creatinine, hypoxanthine, and nucleic acid. The effects in regard to the nitrate concentration were also strikingly the same as with the other substances, the effect of the histidine being most marked in the series of cultures containing potash and phosphate in varying proportions, but no nitrate. The appearance of these cultures is shown in Plate V. They are arranged in pairs of like composition in regard to the mineral salts, phosphate and potash. Cultures marked with the same number, for instance, 56 and 56H, have like fertilizer ratios. The cultures marked with numbers alone have no histidine; the cultures with the letter H have 50 parts per million of the histidine.

As shown in the photograph, the plants in each culture containing histidine, regardless of the composition of the culture solution in phosphate or potash, were larger and showed a much better top and root development.

EFFECT OF HISTIDINE IN CULTURES CONTAINING NO NITRATE.

The green weight of the plants growing in the culture solutions containing no nitrate is shown in Table XV. The larger growth in each of the histidine cultures is apparent. The average increase in the series is 30 per cent greater than the growth without the histidine.

TABLE XV.—*Effect of histidine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without histidine.	With 50 p. p. m. histidine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.250	1.460
46	8	0	72	1.220	1.420
37	16	0	64	1.420	1.700
29	24	0	56	1.200	1.540
22	32	0	48	1.220	1.920
16	40	0	40	1.500	1.880
11	48	0	32	1.200	1.820
7	56	0	24	1.240	2.140
4	64	0	16	1.400	1.700
2	72	0	8	1.140	1.550
1	80	0	0	1.040	1.150

EFFECT OF HISTIDINE IN CULTURES CONTAINING NITRATE.

When some nitrate, 8 parts per million NH_3 as nitrate, was present, the additional effect of the histidine was not as great as in the case where nitrate was entirely absent. This is shown in Table XVI. The total green weight for the 11 cultures was 17.660 grams without histidine and 19.950 grams when this compound was present. The average increase caused by the histidine was 14 per cent greater than that caused by the nutrient salts alone.

TABLE XVI.—*Effect of histidine on growth in culture solutions containing 8 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without histidine.	With 50 p. p. m, histidine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	1.450	1.510
47	8	8	64	1.720	2.000
38	16	8	56	1.570	2.320
30	24	8	48	1.940	1.980
23	32	8	40	1.940	2.600
17	40	8	32	1.940	2.480
12	48	8	24	2.240	2.200
8	56	8	16	2.040	1.800
5	64	8	8	1.600	1.650
3	72	8	0	1.220	1.410

For the series of culture solutions containing 16 parts per million this increase was still less as is shown by Table XVII, the average increase of the series being only 5 per cent. The total growth of the cultures without histidine was 16.770 grams as against 17.690 grams with the histidine.

TABLE XVII.—*Effect of histidine on growth in culture solutions containing 16 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5.	NH_3	K_2O	Without histidine.	With 50 p. p. m. histidine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
58	0	16	64	1.500	1.730
48	8	16	56	1.800	2.140
39	16	16	48	2.100	2.180
31	24	16	40	1.940	2.120
24	32	16	32	2.150	2.380
18	40	16	24	2.100	2.400
13	48	16	16	2.140	2.020
9	56	16	8	1.820	1.440
6	64	16	0	1.220	1.280

The total growth for the series containing 24 parts per million NH_3 as nitrate was 14.380 grams without histidine and 16.390 grams with histidine, the average increase being 14 per cent. What the effect of still larger amount of nitrate would have been is not determinable by this experiment, but it seems probable that the effect is of the same character as in the case of the other substances studied with higher nitrate content.

INFLUENCE OF HISTIDINE ON ABSORPTION.

The analysis of the culture solutions during growth also showed that this compound behaved like those already studied. The total amount of phosphate, potash, and nitrate removed from the solution by the plants in the cultures containing all three constituents was 637.6 milligrams for the control cultures and 645.9 milligrams for the histidine cultures. The phosphate was 166.3 milligrams for the control and 212.8 milligrams for the histidine cultures, an increase of 56.5 milligrams. The potash was 276.6 milligrams for the control cultures and 290.5 milligrams for the histidine cultures, an increase of 13.9 milligrams. The greater growth in the histidine cultures caused, therefore, a somewhat greater absorption of the phosphate and potash. With nitrate, however, the reverse was the case. The normal cultures consumed 194.7 milligrams, whereas the histidine cultures consumed only 142.6, a difference of 47.9 milligrams, this showing that the histidine had caused a decreased consumption of this amount of nitrate, although an increase in growth had taken place in harmony with the behavior of creatinine, creatine, hypoxanthine, and nucleic acid in this respect.

ARGININE.

Arginine has been found in soils in the course of these investigations, but appears to be less stable under soil conditions than histidine, as it has been found in much fewer instances. Arginine, like histidine, is a common cleavage product of protein, and they are usually associated in the more common proteins.

In testing the effect of arginine on plants the carbonate was used, as in the case of histidine, already described, and the experiment otherwise conducted in exactly the same manner and with the same culture solutions, the arginine carbonate being added to the one set of solutions at the rate of 50 parts per million. The wheat seedlings grew from November 2 to November 14, 1911.

Arginine, like histidine, was beneficial to plant growth, and the cultures showed the same general behavior. The growth in the series of cultures containing no nitrate was again the one most influenced by the compound. This is shown by the results given in Table XVIII. The total weight of the 11 cultures without arginine was 13.840 grams against 18.340 grams for the cultures with arginine. This is an increase of 33 per cent in growth. When nitrate was present the arginine had far less effect even than the histidine in producing additional growth, as was shown by the series of cultures containing 8, 16, and 24 parts per million NH_3 as nitrate. The growth in each of these series was approximately the same whether arginine was present or not.

TABLE XVIII.—*Effect of arginine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without arginine.	With 50 p. p. m. arginine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.240	1.520
46	8	0	72	1.220	1.540
37	16	0	64	1.500	1.940
29	24	0	56	1.240	1.720
22	32	0	48	1.100	1.800
16	40	0	40	1.200	1.920
11	48	0	32	1.440	1.920
7	56	0	24	1.200	1.700
4	64	0	16	1.300	1.600
2	72	0	8	1.440	1.640
1	80	0	0	0.960	1.040

The absorption, too, is in line with the results obtained with histidine, although not so definite. The total for the cultures containing all three elements was 672.9 milligrams without arginine and 587.4

milligrams with arginine. The phosphate removal was 196.2 milligrams in the control and 160.7 milligrams in the arginine cultures. The potash removal was 278.6 milligrams in the control and 270.9 milligrams in the arginine cultures. The nitrate consumption was 198.1 milligrams in the control and 155.8 milligrams in the arginine cultures.

CHOLINE.

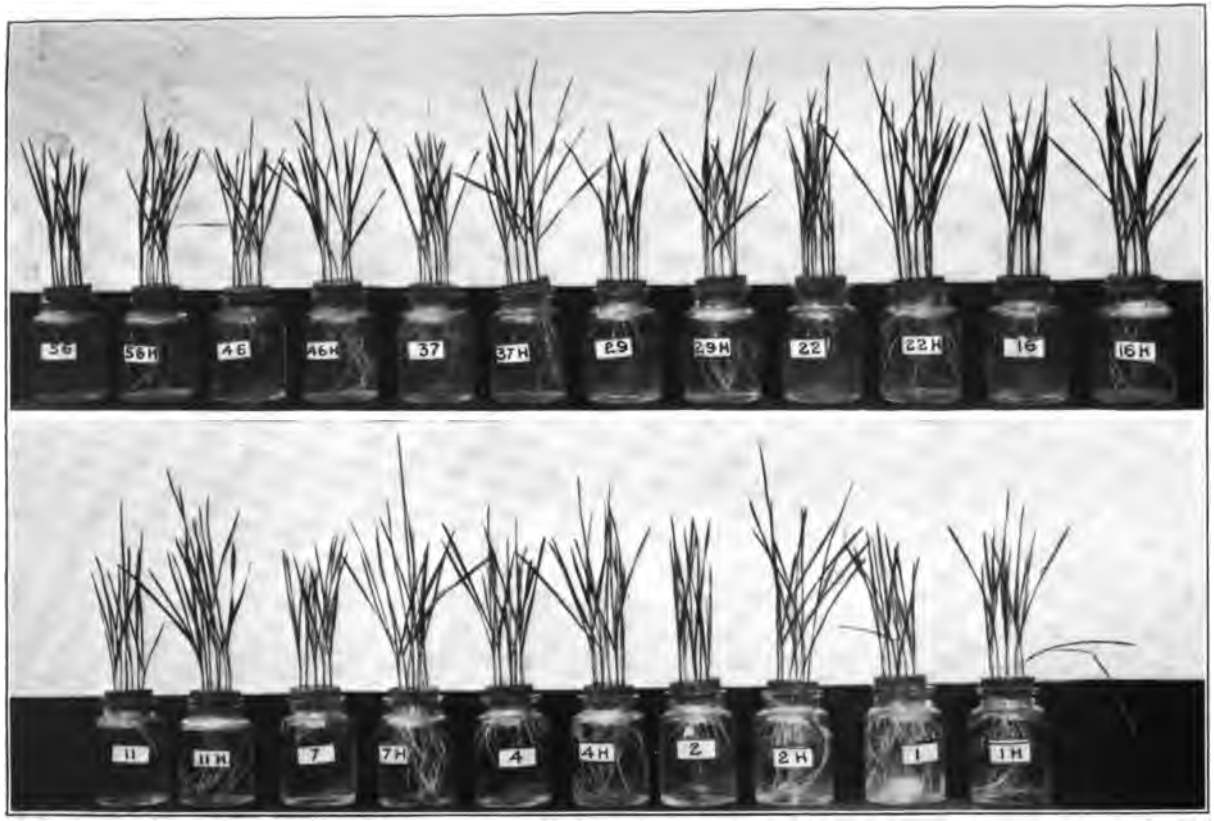
The presence of choline in soils has been demonstrated in this laboratory by the preparation of the characteristic platinum chloride derivative. It is not related to the protein bodies directly, as are the preceding compounds, but forms a part of the molecules of the organic phosphorus compounds of both plants and animals, the lecithins, and is therefore always found when these are decomposed in the laboratory or by natural agencies, such as bacteria. It is also found as a constituent of various plant tissues. The lecithins are closely related to the fats in constitution and are found in all vegetable tissues, being fully as widely distributed as the proteins and sugars. Choline, being formed as a product of this decomposition of the lecithins widely distributed in the vegetable kingdom, is therefore likely to occur in all soils, at least as an intermediary product.

The effect of choline on wheat seedlings was studied in distilled water solutions and the results reported in Bulletin47. The results, though not very decisive, appeared to show that choline is mildly toxic. In the lower concentrations, from 1 to 100 parts per million, the seedlings, more especially the roots, showed increased growth, analogous to the stimulating effect of small amounts of toxic bodies. The concentrations above 100 parts per million were distinctly toxic, producing a retardation in root and top development, although even a concentration of 1,000 parts per million was not fatal to the plants.

It would seem, therefore, that choline is neither decidedly beneficial nor decidedly toxic. If beneficial, it is only so in small amounts; if harmful, it is only so in large amounts.

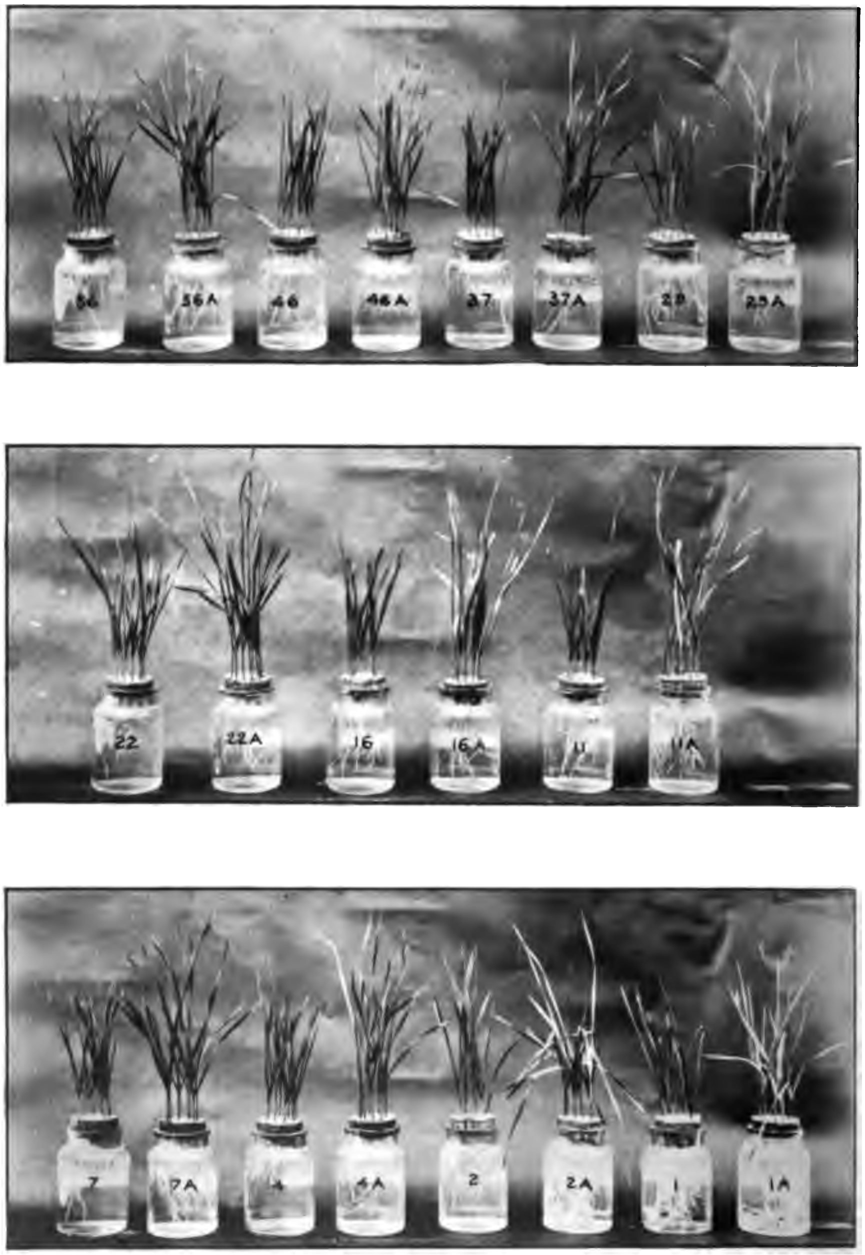
In order to throw a little more light upon the action of choline in the lower concentrations a series of experiments in nutrient solutions using 50 parts per million choline were used. The composition of the nutrient solutions selected for the test are given in Table XIX. It will be seen that three of the cultures contained no nitrate whatever, three contained eight parts, three contained 16, and three 24 parts per million nitrate. The solutions were changed every three days and analyzed. The plants grew from March 18 to March 30, 1912. The green weights obtained at the termination of the experiment are given in the last two columns of Table XIX.

PLATE V.



BENEFICIAL EFFECT OF HISTIDINE, AN ORGANIC SOIL CONSTITUENT, IN CULTURE SOLUTIONS OF DIFFERENT COMPOSITION.

[Cultures marked H contain histidine.]



BENEFICIAL EFFECT OF ASPARAGINE IN CULTURE SOLUTIONS OF DIFFERENT COMPOSITION.

[Cultures marked A contain asparagine.]

TABLE XIX.—*Effect of choline on growth of wheat in nutrient solutions.*

Composition of culture solution.			Green weight of culture.	
P_2O_5	NH_3	K_2O	Without choline.	With 50 p. p. m. choline.
P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	24	1.650	1.640
40	0	40	1.600	1.920
24	0	56	1.400	1.620
56	8	16	1.840	2.420
40	8	32	2.300	2.500
24	8	48	2.100	2.050
48	16	16	2.200	2.405
32	16	32	2.700	2.650
16	16	48	2.100	2.305
48	24	8	1.600	1.550
32	24	24	2.750	2.630
16	24	40	2.660	2.650

With this concentration of choline—50 parts per million—the green weight was greater than the control in two cases out of three in the first three groups where nitrate was absent or low. The last group having 24 parts per million nitrate, the choline produced no increase in growth, a decrease in fact being observable. The first group, with no nitrate present, showed an average increase in growth amounting to 9 per cent; the second group, with 8 parts per million nitrate, showed an average increase of 14 per cent; the next group, 5 per cent increase; the last, 3 per cent decrease. In a minor way this behavior is similar to that shown by the nitrogenous compounds beneficial to growth already given, and it is interesting to observe if the nitrate consumption of the choline plants is in harmony with this action. This was found to be the case when the analytical data obtained were considered. The results were as follows: The phosphate absorption was, for the normal cultures, 117.3 milligrams, and for the choline cultures, 118.8 milligrams; the potash absorption was, for the normal cultures, 180.5 milligrams, and for the choline cultures, 175.4 milligrams; the nitrate absorption was, for the normal cultures, 103.3 milligrams, and for the choline cultures only 85.2 milligrams. The potash and phosphate absorptions are practically the same, but the nitrate consumption of the plants is less in the case of the choline cultures by 18.1 milligrams in harmony with the effect of the other compounds studied.

It would seem, therefore, that we must conclude that in lower concentrations of choline the substance is slightly beneficial to plant growth and probably utilized by the plant as a source of nitrogen, since the nitrate consumption is lessened, although plant growth is slightly increased.

PICOLINE CARBOXYLIC ACID.

Picoline carboxylic acid has been isolated from soils and, while the difficulty of its separation has not made it possible to ascertain to what extent it may be a common constituent, it has, nevertheless, been found in widely separated and distinctly different soils in the eastern United States and in Hawaii.[1] Picoline carboxylic acid is related to uvitonic acid which can be made from pyruvic acid and ammonia. Pyruvic acid is, however, a constant secondary decomposition product of protein, so that the most that can be said at present is that picoline carboxylic acid may arise from the splitting and decomposition of protein in soil.

The effect of picoline carboxylic acid on plant growth was tested in connection with the above investigation regarding its occurrence. It was tested in distilled water cultures in concentrations of 1 to 200 parts per million.

TABLE XX.—*Effect of picoline carboxylic acid on wheat seedlings.*

Solution.	Relative growth.
Control in distilled water	100
Picoline carboxylic acid, 1 p. p. m	95
Picoline carboxylic acid, 10 p. p. m	101
Picoline carboxylic acid, 50 p. p. m	98
Picoline carboxylic acid, 100 p. p. m	89
Picoline carboxylic acid, 200 p. p. m	70

From the figures it must be concluded that picoline carboxylic acid is toxic, at least moderately so. In the solutions containing 100 to 200 parts per million, in addition to the decreased weight of the plants, the roots showed the abnormal appearance characteristic of the presence of an injurious compound, little growth, with root tip first darkened, then club-shaped or hooked.

The effect of the related uvitonic acid on plants, inasmuch as it has not yet been found in soils, will be given in another section of this bulletin. It was more harmful to growth than the picoline carboxylic acid. It would seem that the nitrogen in these compounds is not directly utilizable by the higher plants. Molds grow very well in solutions of picoline carboxylic acid and are, in fact, kept out of solutions only with difficulty when the compound is being crystallized.

STUDY OF THE EFFECT OF OTHER NITROGENOUS COMPOUNDS ON GROWTH AND ABSORPTION.

In addition to the study of the nitrogenous soil constituents in the preceding portion of this bulletin, other data have been obtained for nitrogenous compounds not yet isolated from soils.[1] It was, in fact, along these lines that the earlier investigations were conducted before definite constituents had been isolated from soils. The difficulties encountered in the isolation of definite soil constituents were then so great and the progress necessarily so slow that it was thought that the synthetic way of adding compounds of known composition, known properties, and known derivation from plants to culture media, in order to study their properties and the effect which they might have upon plant growth, would answer the question whether such compounds are toxic or beneficial to plants much sooner than could possibly be done by first isolating them from the soil and then trying their properties. Proceeding in this way it was possible to reach a broader survey of the effect of organic plant remains and get a clearer conception of the manner in which these function in the soil. In extending the observations made in the earlier work along these lines, this same principle has controlled the work and it is thus possible to be not only a little ahead of the actual isolation of compounds, but also obtain a broader view of the subject, especially in regard to their function in the soil. In this section are presented the results of the investigations made in this laboratory with a number of compounds allied to the nitrogenous constituents already found in soils, as well as with some which future investigations may show to be present in soils.

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[1] Organic Nitrogen in Hawaiian Soils, by Edmund C. Shorey. Rept. Hawaii Agr. Expt. Sta., 1906, p. 37. The Isolation of Harmful Organic Substances from Soils by Oswald Schreiner and Edmund C. Shorey. Bul. No. 53, Bureau of Soils, U. S. Dept. Agr.

ASPARAGINE.

Asparagine is a water soluble form of organic nitrogen material which is relatively abundant in plants. It was first found in the young shoots of asparagus and subsequently in a large number of other plants representing many different families.

This experiment on the effect of asparagine was carried out in every way as described with nucleic acid and some of the other compounds in the previous section. All of the fertilizer combinations, 66 in number, were used in the cultures, and to a second set 50 parts per million of asparagine were added to each culture. The wheat seedlings grew from November 13 to November 25, 1909. The solutions were changed every three days and analyzed.

The total green weight of the asparagine set was 148.2 grams, against 134.9 grams for the normal or control set, an increase of 9 per cent as an average of all the asparagine cultures.

The appearance of the two sets of cultures left no doubt concerning the beneficial action of this compound, an effect again most marked in the series of cultures containing no nitrate. This series of cultures is reproduced in Plate VI. Cultures marked with the same number, for instance 56 and 56A, have the same proportions of potash and phosphate. The cultures marked with the number alone contain no asparagine; the cultures with the letter A have 50 parts per million of asparagine. It will be seen that each culture containing asparagine, no matter what the proportion of phosphate and potash may be, is larger than the cultures growing in a similar solution without the asparagine. The effect of the asparagine shows itself quite early. In Plate VII, figure 1, for instance, are shown the plants growing in solution No. 16, containing 40 parts per million each of potash and phosphate, without and with asparagine, photographed at the end of 6 days.

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[1] Certain Organic Constituents of Soils in Relation to Soil Fertility, by Oswald Schreiner and Howard S. Reed. Bul. No. 47, Bureau of Soils, U. S. Dept. Agr. (1907).

The effect of the asparagine is already distinctly noticeable, and becomes more decided as the experiment progresses, as is shown, for instance, by comparing this photograph with the same plants shown in Plate VI, cultures 16 and 16A, photographed six days later. The weight of the tops of these two cultures at the end of the experiment was, respectively, 1.223 grams and 2.199 grams, an increase of 80 per cent.

EFFECT OF ASPARAGINE IN CULTURES CONTAINING NO NITRATE.

The green weight of the tops taken at the termination of the experiment are given in Table XXI for the entire series containing no nitrate. All of the cultures with asparagine present show a marked increase in weight. The total weight of the 11 cultures without asparagine was 13.714 grams against 20.478 grams with asparagine, thus showing an increase of 47 per cent as an average effect in the various cultures without nitrate.

TABLE XXI.—*Effect of asparagine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without asparagine.	With 50 p. p. m. asparagine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.385	1.832
46	8	0	72	1.368	1.644
37	16	0	64	1.382	1.742
29	24	0	56	1.119	1.825
22	32	0	48	1.393	2.145
16	40	0	40	1.223	2.199
11	48	0	32	1.167	1.932
7	56	0	24	1.243	2.199
4	64	0	16	1.313	1.909
2	72	0	8	1.311	1.775
1	80	0	0	0.810	0.975

EFFECT OF ASPARAGINE IN CULTURES CONTAINING NITRATE.

In Table XXII are given the green weights obtained in the next series of cultures, all of which contain the uniform amount of eight parts per million NH_3 as nitrate, with varying quantities of potash and phosphate. The effect of asparagine is still noticeable in these green-weight figures as it was while the plants were growing, but the additional effect is much less marked than in the absence of all nitrates shown in the preceding table. The total growth in this series without asparagine was 19.298 grams, against 22.075 grams with asparagine, an additional increase of 14 per cent due to asparagine. When no nitrate was present this additional effect of the asparagine was 47 per cent.

TABLE XXII.—*Effect of asparagine in culture solutions containing 8 p. p. m. NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without asparagine.	With 50 p. p. m. asparagine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	1.880	1.830
47	8	8	64	1.912	2.275
38	16	8	56	2.234	2.184
30	24	8	48	2.244	2.580
23	32	8	40	2.027	2.665
17	40	8	32	1.839	2.433
12	48	8	24	1.961	2.545
8	56	8	16	2.073	2.240
5	64	8	8	1.863	2.068
3	72	8	0	1.265	1.255

In Table XXIII the green weight for the series of cultures containing 16 parts per million NH_3 as nitrate is given. Without the asparagine the total weight of these cultures is 19.917 grams, with asparagine it is 21.253 grams, or only an increase of 7 per cent. The additional effect of asparagine was still less in the 24 parts per million NH_3 cultures, and with the higher concentrations this effect became even uncertain.

TABLE XXIII. *Effect of asparagine on growth in culture solutions containing 16 p. p. m. of NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without asparagine.	With 50 p. p. m. asparagine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
58	0	16	64	1.905	2.379
48	8	16	56	2.270	2.489
39	16	16	48	2.510	2.255
31	24	16	40	2.518	2.795
24	32	16	32	2.289	2.660
18	40	16	24	2.633	2.566
13	48	16	16	2.256	2.545
9	56	16	8	2.219	2.245
6	64	16	0	1.317	1.319

While the effect of the asparagine decreased with increasing nitrate so far as additional effect on growth is concerned, it had, nevertheless, a conserving effect upon the amount of nitrate left in the solution during the time the plants were growing, as is shown by the analysis of the solutions.

The total potash, phosphate, and nitrate removed from the cultures containing all three of these was 1,109.6 milligrams for the normal and 1,117.0 milligrams for the cultures containing asparagine. Of these totals; the control cultures removed 201.2 milligrams and the asparagine cultures 326.0 milligrams of phosphate; the control 471.2 milligrams and the asparagine cultures 485.6 milligrams of potash; the control 437.2 milligrams and the asparagine cultures only 305.4 milligrams of nitrate. Potash and phosphate were absorbed in somewhat larger quantities by the asparagine cultures, but the nitrate consumption was much decreased, 131.8 milligrams less than the control cultures.

ASPARTIC ACID.

Aspartic acid has been found in young sugar cane and in the molasses of the sugar beet. It is probably not widely distributed in nature, but has been shown to exist in seedlings of the bean and pumpkin. Aspartic acid is related to asparagine, which is its monoamide, and can be prepared therefrom by boiling with hydrochloric acid. It is also formed by the decomposition of proteins with dilute sulphuric acid.

Its physiological action on higher plants is not very definitely determined. Aspartic acid has been tested by Prianischnikoff and Lebedeff with barley, Brown with barley germs, Molliard with radishes, Hutchinson and Miller with peas, and in this laboratory aspartic acid was tested with wheat seedlings, using concentrations ranging between 1 and 750 parts per million. The plants were killed in solutions stronger than 500 parts per million, presumably on account of the acid properties of the solution. In the solution containing 100 parts per million there was little injury, and below that no injury.

Hutchinson and Miller used the sodium salt and were able to show an increase in the nitrogen of peas grown in solutions of sodium aspartate.

LEUCINE.

Leucine is a very common decomposition product of proteins. It also occurs in the fly agaric, in vetches, lupine, gourd, molasses of the sugar beet, potatoes, blighted corn, etc. It undoubtedly exists in soil in a transitory state; as is common with other monoamino acids it decomposes readily under soil conditions. In fact, the leucine showed decomposition even in the cultures in these experiments. At the end of three days when the solutions were changed they showed the presence of ammonia by Nessler's reagent and had a distinct unpleasant odor. This was true whether plants grew in the solutions or not, as was demonstrated in tests conducted in connection with this experiment.

Two sets of cultures with and without leucine were set up, the number and composition of the cultures being as in the case of histidine, consisting of the 4 series of cultures containing 0, 8, 16, and 24 parts per million of NH_3 as nitrate, respectively, the cultures with higher amounts of nitrate being omitted. The wheat seedlings grew from October 18 to October 30, 1911. While beneficial, the effect of the leucine was not nearly so marked as in the case of asparagine, histidine, etc. The total weight of normal cultures was 72.9 grams against 76.2 grams in the leucine cultures, an increase of less than 5 per cent.

EFFECT OF LEUCINE IN CULTURES CONTAINING NO NITRATE.

Table XXIV shows the green weight of the series of cultures containing no nitrate. The leucine cultures shown in the last column are greater than the normal or control cultures given in the fifth column. The total for the normal cultures is 15.362 grams against 17.172 grams for the leucine cultures, an increase of 11 per cent.

TABLE XXIV.—*Effect of leucine on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without leucine.	With 50 p. p. m. leucine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.540	1.640
46	8	0	72	1.510	1.740
37	16	0	64	1.540	1.752
29	24	0	56	1.500	1.700
22	32	0	48	1.500	2.000
16	40	0	40	1.400	1.800
11	48	0	32	1.542	1.740
7	56	0	24	1.240	1.250
4	64	0	16	1.320	1.320
2	72	0	8	1.320	1.340
1	80	0	0	0.950	0.890

EFFECT OF LEUCINE IN CULTURES CONTAINING NITRATE.

Table XXV gives the green weight for the cultures containing 8 parts per million NH_3 as nitrate. The total for the series was, control cultures 20.139 grams, leucine cultures 20.760 grams, an increase of 3 per cent.

TABLE XXV.—*Effect of leucine on growth in culture solutions containing 8 p. p. m. NH_3 as nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without leucine.	With 50 p. p. m. leucine.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
57	0	8	72	1.620	2.020
47	8	8	64	2.010	2.340
38	16	8	56	2.200	2.300
30	24	8	48	2.220	2.320
23	32	8	40	2.220	2.300
17	40	8	32	2.520	2.040
12	48	8	24	2.449	2.200
8	56	8	16	1.940	2.140
5	64	8	8	1.540	1.700
3	73	8	0	1.420	1.400

In the next two series of cultures the additional effect attributable to leucine had entirely disappeared. Whether this result, as well as the lower results obtained in the above series with leucine, are attributable to a lower efficiency of this compond or to the fact that only a part of it was available before decomposition set in, can not be definitely decided by this experiment. This much is certain, however, that the decomposition products, including ammonia and probably other amines, were not as beneficial as the other nitrogenous compounds studied. It is probable that their formation reduced the effect of leucine rather than augmented it.

The consumption of nitrates as shown by the determinations on the three-day changes were much nearer alike in the two sets, the normal and the leucine set, than in the case of any of the compounds thus far described, a result which is in harmony with the small increase in growth attributable to the leucine. The nitrate consumption in the normal cultures was 221.9 milligrams against 196.6 milligrams in the leucine cultures, a decreased consumption of only 25.3 milligrams.

ALLANTOIN.

Allantoin occurs in some animal fluids and has also been found in the young leaves of the plane tree, in the sprouts of Acer species and horse-chestnut bark, and in beet juice. The allantoin in the animal body is supposed to be a product of the oxidative destruction of purine bases, and in particular of uric acid. Shibata, working with *Aspergillus niger*, showed that this mold had no action on allantoin. Brown showed an increase of nitrogen in the case of excised barley embryos due to allantoin, behaving in this respect like choline.

The effect of allantoin on plants was tried in the same general way as described for the other compounds. The test lasted from May 7 to May 19, 1911. The control and the allantoin set showed no perceptible difference as a whole, although the no nitrate series was

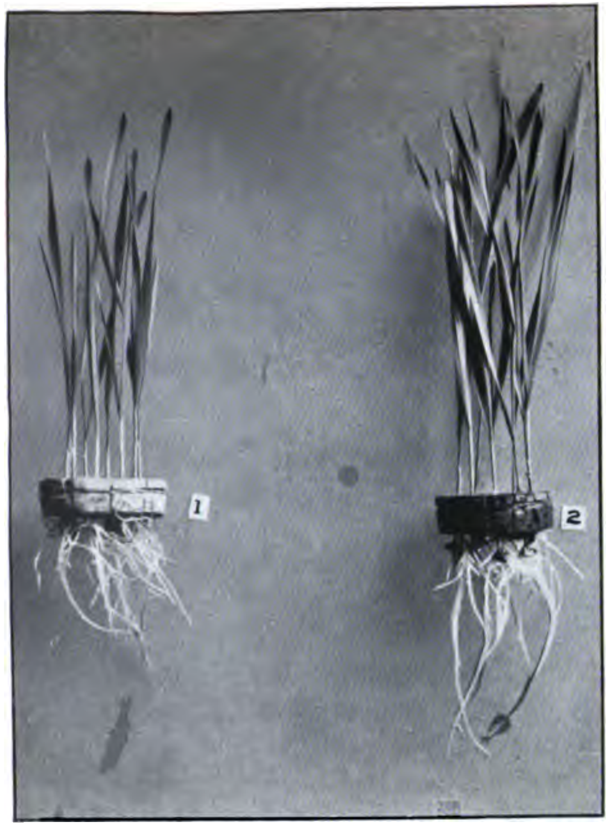


FIG. 1.—BENEFICIAL EFFECT OF ASPARAGINE SHOWN BY SIX-DAY-OLD PLANTS.

[No. 1, without asparagine; No. 2, with asparagine.]

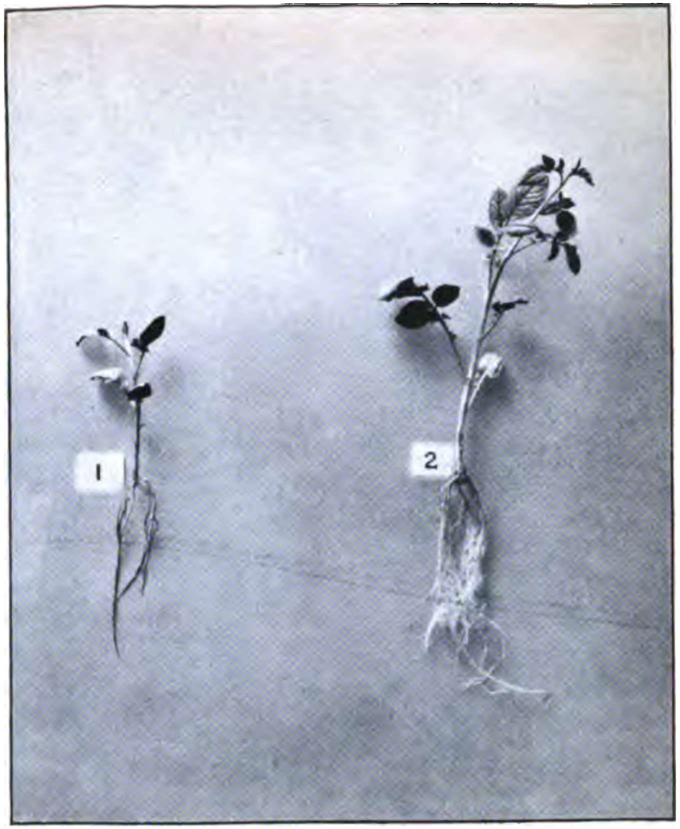
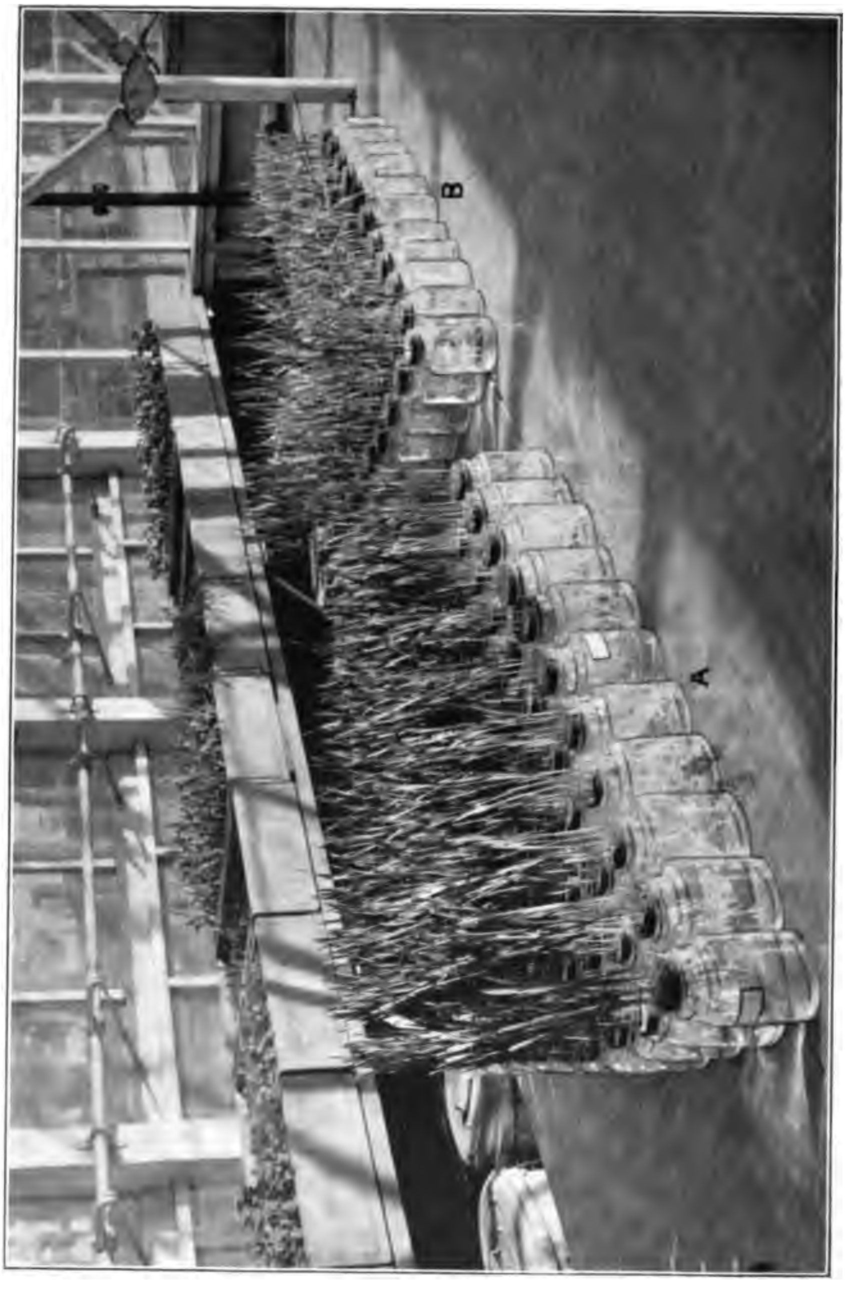


FIG. 2.—EFFECT OF SOLANINE ON POTATO SEEDLINGS.

[No. 1, with solanine; No. 2, without solanine.]

PLATE VIII.



HARMFUL EFFECT OF GUANIDINE.

[A, control set of cultures; B, set containing guanidine.]

better, a fact also borne out by the green weights of this series as shown in Table XXVI. The total green weight of the control cultures was 17.493 grams against 21.595 grams for the allantoin cultures, an increase of 23 per cent.

TABLE XXVI.—*Effect of allantoin on growth in culture solutions containing no nitrate.*

Culture number.	Fertilizer ingredients in culture solution.			Green weight of culture.	
	P_2O_5	NH_3	K_2O	Without allantoin.	With 50 p. p. m. allantoin.
	P. p. m.	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*
56	0	0	80	1.509	1.650
46	8	0	72	1.400	1.959
37	16	0	64	1.820	1.928
29	24	0	56	1.608	2.050
22	32	0	48	1.600	2.220
16	40	0	40	1.650	2.200
11	48	0	32	1.820	2.170
7	56	0	24	1.620	2.320
4	64	0	16	1.748	2.028
2	72	0	8	1.594	1.920
1	80	0	0	1.124	1.150

The next series of cultures, those containing 8 parts per million nitrate, showed almost no increase, being 24.121 grams for the control and 24.990 grams for the allantoin cultures. The solutions still higher in nitrate became very uncertain and even showed some decrease, so that the total growth of the 66 cultures in each set was practically the same, namely, for the control 163.7 grams and for the allantoin set 163.6 grams. Allantoin appears therefore to be a body which has an effect on plant growth, when no nitrate is present, but as soon as even the smallest amount of nitrate is available to the plant, the allantoin has no further effect on growth. We would conclude from this that allantoin is of only indifferent value as a direct nutrient for wheat.

CYSTEIN.

Cystein and cystin are closely related compounds. Cystin is a constant and abundant dissociation product of most albumins.

Although often accompanied by cystein, the cystin is held to be the primary dissociation product of the albumin. Cystein is formed from cystin by reduction, which can be accomplished in the laboratory with granulated tin and hydrochloric acid.

The crystalline cystein so prepared was used in these experiments. Owing to the fact that cystein in aqueous solution is oxidized to cystin on exposure to air, the result of the tests may not be wholly due to cystein alone, as it is probable that a portion at least went over into cystin. Of the effect of the latter by itself we have no evidence other than that from an earlier preliminary experiment, in which the cystin appeared to be so insoluble in the culture solutions that no noticeable effect on growth was produced. It would, therefore, appear that neither cystin nor cystein had any decided effect on plant growth, as is shown in the following.

The effect of cystein on plants was tried by adding 50 parts per million to each solution, the total number of 66 cultures being used in the test, a control set being grown at the same time. The solutions were changed every three days, but no analyses were made. The wheat seedlings grew from January 17 to January 29, 1912.

No perceptible difference in the appearance of the two sets of cultures was noticed during growth. The green weight of tops taken at the termination of the experiment likewise showed no appreciable difference. The total green weight for the control cultures was 125.6 grams and for the cystein cultures was 122.2 grams. It was obvious that the cystein in these cultures had no such effect as that shown to exist in the case of asparagine, histidine, creatinine, etc. While the series of no nitrate cultures showed a trifling increase, the 8 parts per million nitrate series showed a corresponding decrease in harmony with the results of the sets as a whole. Nor did the results obtained in the tests show any other special characteristics in regard to a different effect in the cultures of varying composition in phosphate, potash, and nitrate. In Table XXVII the results are grouped according to whether the cultures are mainly phosphatic, mainly nitrogenous, or mainly potassic, by combining all the cultures in the subtriangles 1–16–21, 21–61–66, and 16–56–61 (see fig. 1), respectively.

TABLE XXVII.—*Showing the effect of cystein with fertilizer mixtures mainly phosphatic, mainly nitrogenous, and mainly potassic.*

Culture solutions.	Green weight.	
	Without cystein.	With 50 p. p. m. cystein.
	Grams.	*Grams.*
Mainly phosphatic group	33.34	32.63
Mainly nitrogenous group	40.10	39.31
Mainly potassic group	37.74	36.18
All other cultures	14.41	14.06
Total set	125.59	122.18

All these groups are in harmony in showing a slightly depressed growth, but otherwise reveal nothing of especial interest.

GUANIDINE.

It should be mentioned at the very outset that guanidine behaved in every respect differently than the compounds hitherto considered, having a very decided physiological action and toxic influence on growth.

Guanidine has been found in some plants. It may arise from the oxidation of arginine. Arginine is a decomposition product of proteins and exists in plants, and has also been found in soils, as already mentioned. Interesting in this connection is the appearance of guanidine in seedlings, as reported by Schulze,[1] which probably results by further changes from arginine. Guanidine can also be formed by the oxidation of guanine in the laboratory.

Guanidine was first shown to be toxic to plants by Kawakita[2] and later in this laboratory.[3] According to Shibata,[4] who studied the effect of *Aspergillus niger* on a number of nitrogenous compounds, this mold had no effect on guanidine. Hutchinson and Miller report guanidine among the nitrogenous compounds assimilated by plants.

In the earlier experiments in this laboratory the guanidine carbonate was studied in various concentrations of distilled water. The wheat plants were killed in solutions stronger than 100 parts per million in 9 days. In all the lower concentrations, including 1 part per million, the wheat plants were seriously injured.

This harmful effect of guanidine has since been more thoroughly studied. This time the nutrient culture solutions, 66 in number, were used, comprising all the combinations of potash, phosphate, and nitrate, as explained in the section on the methods used in these investigations. Two sets of these cultures were prepared—one was used as a control; to the other was added 25 parts per million of guanidine carbonate to each culture. The wheat seedlings grew from February 15 to February 27, 1911. The solutions were changed every three days and analyzed.

For the first few days no difference was noticeable between the control and the guanidine set. About the fifth day bleached spots appeared on the leaves in some of the cultures, producing an effect like a plant disease. These diseased spots on the leaves spread and became larger and more numerous. The spots appeared first on a few cultures, and apparently spread to other cultures, but when the cultures were arranged in the order of their composition the reason for this became evident. The guanidine effect showed itself first in the cultures high in nitrate and then spread to those lower in nitrate, until the series of no nitrate content was reached. In this series the guanidine effect was scarcely discernible. As the plants grew older the guanidine effect became more and more marked, the bleached spots coalesced and appeared most marked in the lower part of the leaves, the leaves would finally break, presenting on the whole an effect similar to that produced by a wilt disease, and was accompanied with considerable bleaching of the green parts of the plant. This, at least, was the effect in all of the cultures containing nitrate, and was the more marked the higher the nitrate. The series containing no nitrate, however, retained its green color and was not subject to collapse or wilting, although here and there some bleached dots appeared.

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[1] Zeit. physiol. Chem., 17, 197 (1892).

[2] Bul. Coll. Agr., Tokyo, 6, 182 (1904).

[3] Bul. 47, Bureau of Soils (1907), p. 27.

[4] Hofmeister's Beiträge, 5, 384 (1904).

In Plate VIII are shown the two sets of cultures. A is the normal or control set and B the guanidine set. The distinctly destructive effect of the guanidine is apparent in the blighted appearance of set B in striking contrast to the fine growth in the control cultures, which is even more marked than the photograph can show, because of the deep green color of the normal set, contrasted with the bleached appearance of the guanidine set.

In Plate IX a nearer and better view is had of this guanidine set. The plants are arranged according to the composition of their culture solutions, in the form of a triangle as suggested by figure 1. By this arrangement the highest nitrate culture appears at *N*, the highest phosphate culture at *P*, and the highest potash culture at *K*, the position of intermediate cultures becoming apparent by glancing at figure 1. It is apparent that the poorest plant development occurs in those cultures high in nitrate, but is distinctly noticeable in every culture except in the line of cultures from *P* to *K*, which is the series containing no nitrate. The plants in this line of cultures are firm and erect as can be seen in the photograph. In actuality this difference is further accentuated by the nearly normal green color of this series, whereas all other cultures, in addition to the dilapidated condition, had a decided bleached appearance.

The effect of the nitrate in increasing the harmful effect of guanidine is also shown by the weight of the tops taken at the termination of the experiment. In Table XXVIII the first column gives the series of cultures which have like nitrate content. The amounts of nitrate in each culture of these series are given in the second column. The third and fourth columns give the weight of the tops of the plants grown in the cultures without and with 25 parts per million of guanidine carbonate. It is at once apparent that the guanidine is very harmful to growth. The total green weight of the 66 cultures in the normal set was 151.2 grams against only 99.5 grams in the guanidine set. Placing the normal at 100, the growth in the guanidine set becomes 66. The last column gives the relative growth in each of the series of uniform nitrate content in the set. The culture which contained 80 parts per million NH_3 as nitrate gave a relative weight of only 31 or a decrease in growth of 69 per cent, whereas in the series of cultures which contained no nitrate the relative growth was 94 or a decrease of 6 per cent only below the control. As shown in the table, the relative weight of tops obtained increased with decreasing nitrate content.

TABLE XXVIII.—*Effect of guanidine on growth as influenced by nitrate. Experiment I.*

Culture series. (See fig. 1.)	NH_3 as nitrate in fertilizer mixture.	Green weight of cultures.		Relative weight (without guanidine=100).
		Without guanidine.	With 25 p. p. m. guanidine.	
	P. p. m.	*Grams.*	*Grams.*	
66	80	1.659	0.520	31
55-65	72	4.178	1.990	47
45-64	64	6.860	3.412	48
36-63	56	9.449	5.031	53
28-62	48	12.359	6.874	55
21-61	40	15.998	8.394	52
15-60	32	18.649	11.491	62
10-59	24	21.691	13.602	62
6-58	16	23.327	15.709	67
3-57	8	20.923	17.288	83
1-56	0	16.156	15.195	94

This effect of guanidine on growth, and especially the harmful influence of the nitrate, was considered so remarkable that the entire experiment was repeated with absolutely the same results. The plants grew from March 17 to March 29, 1911. Again the effect of the guanidine did not appear until about five days had elapsed, and again it showed itself first, and later most marked, in the high nitrate solutions. Again the no nitrate cultures were left practically unharmed. The total green weight for the normal set was 163.9 grams and in the guanidine set it was 116.3 grams, or a relative green weight of 71. The weight of the tops in the different nitrate series are given in Table XXIX, the arrangement being exactly the same as in Table XXVIII. The last column, giving the relative green weight of the different nitrate series, again shows the greater harmfulness of the guanidine in the series containing nitrate, which is especially marked in those high in nitrate.

TABLE XXIX.—*Effect of guanidine on growth as influenced by nitrate. Experiment II.*

Culture series. (See fig. 1.)	NH_3 as nitrate in fertilizer mixture.	Green weight of cultures.		Relative weight (without guanidine=100).
		Without guanidine.	With 25 p. p. m. guanidine.	
	P. p. m.	*Grams.*	*Grams.*	
66	80	2.201	1.003	46
55-65	72	4.040	2.040	50
45-64	64	7.275	4.021	55
36-63	56	10.359	5.996	57
28-62	48	13.387	7.544	56
21-61	40	17.394	10.110	58
15-60	32	20.821	13.204	63
10-59	24	22.769	16.952	74
6-58	16	25.614	18.141	71
3-57	8	24.097	21.112	81
1 56	0	15.969	16.164	100

In the first experiment the solutions were also analyzed for phosphate, nitrate, and potash. The results show a marked decrease in the absorption of the nutrient salts on the part of the guanidine plants, although the roots themselves were not noticeably affected, as is apparent from the plants visible in Plates VIII and IX.

The total phosphate, nitrate, and potash removed by the normal plants were 1,608.9 milligrams, against only 1,088.5 milligrams in the guanidine set. The phosphate removal was 427.3 milligrams in the control and 287.0 milligrams in the guanidine set; the potash was 723.7 milligrams for the control and 496.7 milligrams for the guanidine set; the nitrate was 457.9 milligrams for the control cultures and 304.8 milligrams for the guanidine cultures.

The effect of guanidine was further studied using plants other than wheat. In Plate X, figure 1, is shown its effect on corn growing in culture solution No. 41, containing 16 parts per million phosphate, 32 parts per million nitrate, and 32 parts per million potash. Figure 2 shows the effect of guanidine on cowpeas, the control and guanidine cultures being in duplicate. The culture solution is No. 41. Plate XI, figure 1, shows its effects on the potato plant. With all of these plants the harmful effect on growth is clearly shown and the same general physiological action was manifested as in the case of wheat.

In regard to the influence of nitrate in increasing the harmfulness of guanidine, some further studies were made which indicate that the beneficial nitrogen compounds studied in this paper do not share this property with the nitrate.

To solution No. 41, containing 16 parts per million phosphate, 32 parts per million nitrate, and 32 parts per million potash, 25 parts per million of guanidine were added, and wheat seedlings were grown in this solution as well as in a control without the guanidine. A similar set of cultures was prepared with and without guanidine, but with this difference, that the nitrate was omitted entirely and an equivalent amount of nitrogen in the form of asparagine added to the culture solution. The plants grew from March 10 to March 23, 1911.

The characteristic effects of guanidine were noticed in the culture containing nitrate, but did not appear in the culture containing asparagine. The appearance of the cultures is shown in Plate XI, figure 2, where No. 1 is the control with nitrate and 3 the control with asparagine. Nos. 2 and 4 are the guanidine cultures to be compared with each other and with their respective controls. No. 2 shows the wilting effect of the guanidine, as well as the decreased growth. The colors of the various cultures brought out the difference even more strikingly. The green weights given in Table XXX bear out the same point.

Table XXX.—*Effect of guanidine in culture solutions containing nitrogen as nitrate and as asparagine.*

Culture solution.	Green weight.	Culture solution.	Green weight.
	Grams.		*Grams.*
$CaH_4(PO_4)_2$ $NaNO_3$ K_2SO_4	4.0	$CaH_4(PO_4)_2$ Asparagine K_2SO_4	3.5
$CaH_4(PO_4)_2$ $NaNO_3$ K_2SO_4 +25 p. p. m. guanidine	2.5	$CaH_4(PO_4)_2$ Asparagine K_2SO_4 +25 p. p. m. guanidine	3.3

The soil constituent, creatinine, was later also tried in this same manner. The plants grew from October 19 to November 1, 1911. The results of this test are given in Table XXXI, and again the guanidine effect is not shown in the culture containing the creatinine.

Table XXXI.—*Effect of guanidine in culture solutions containing nitrogen as nitrate and as creatinine.*

Culture solution.	Green weight.	Culture solution.	Green weight.
	Grams.		*Grams.*
$CaH_4(PO_4)_2$ $NaNO_3$ K_2SO_4	3.4	$CaH_4(PO_4)_2$ Creatinine K_2SO_4	3.0
$CaH_4(PO_4)_2$ $NaNO_3$ K_2SO_4 +25 p. p. m. guanidine	2.4	$CaH_4(PO_4)_2$ Creatinine K_2SO_4 +25 p. p. m. guanidine	3.0

TYROSINE.

Tyrosine is one of the most important and most widely distributed protein hydration products. Tyrosine exists as such in many plant organs, especially those which contain appreciable quantities of protein, and is to be regarded as a splitting product of protein. It has also been found in certain fungi. The tyrosine group appears to be present in the protein molecule, and to it are due some of the reactions shown by this class of bodies. Lutz's early work showed tyrosine to be harmful, but in a later article with a different species of *Cucumis* he obtained a beneficial result. Brown failed to show that tyrosine was utilized by excised barley embryos.

Tyrosine was tested in these laboratories in 1907 by growing wheat seedlings in various concentrations, using distilled water. At a concentration of 100 parts per million it killed the roots and injured the tops. It was even injurious in a concentration as low as 16 parts per million. During the first few days the roots showed a pathological condition, and before the tenth day they were dead. At a concentration of 1 part per million there was a very slight increase in growth over the controls. The physiological action of different samples of tyrosine was not always of equal intensity.

Upon long standing with exposure to air the tyrosine solutions underwent change and became quite dark in color, resembling manure extract. The changes wrought were probably the same as those produced by the enzyme tyrosinase, which oxidizes tyrosine to homogentisinic acid, which in time gives rise to the dark-colored compounds.

This darkened solution and a fresh tyrosine solution was used in equivalent strengths of 16 parts per million, for growing wheat seedlings, together with a control in pure distilled water. In a few days the plants in the two solutions showed pronounced differences, which became greater as the experiment was continued. The plants in the fresh tyrosine were more poorly developed than those grown in distilled water. The leaves were narrow and beginning to die at the tips. The roots were dead and had become slimy. The plants in the discolored tyrosine had made excellent growth. The leaves were rich, green, broad, and making vigorous growth. The roots showed a similar good development.

Since the above work was done the work of Molliard on radishes confirms the harmful action of tyrosine.

GLYCOCOLL.

Glycocoll, amido-acetic acid, is one of the simpler protein degradation products found where decomposition is occurring. Its effect on plants has been ascertained by several investigators, who have uniformly found it to be beneficial. In the experiments of this laboratory in which water solutions of glycocoll of varying concentrations were used, the effect on wheat seedlings was beneficial in a concentration of 1,000 parts per million and less. Hutchinson and Miller in one of their pea cultures showed that the nitrogen content of the plant was increased by the use of glycocoll, although a slight decrease was noticed in another culture.

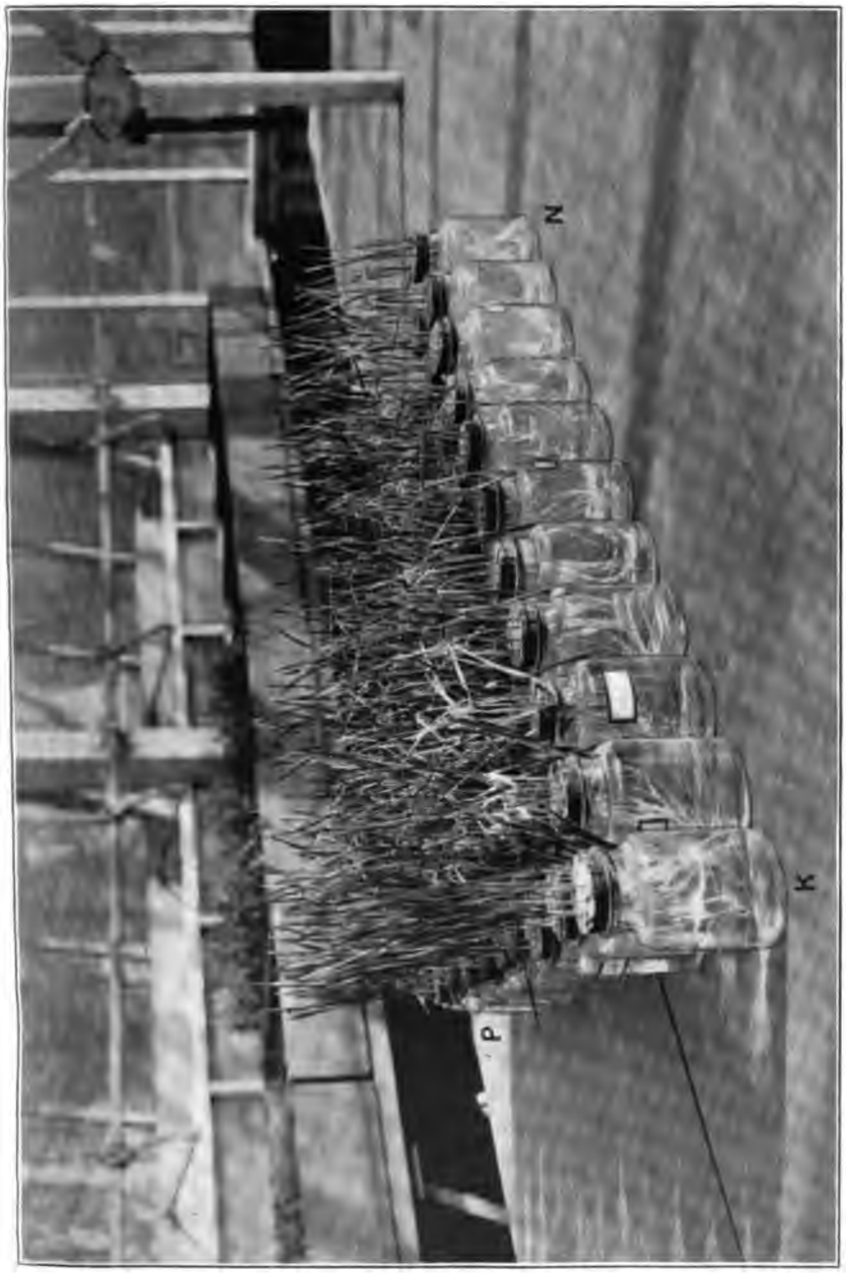
ALANINE.

Alanine does not appear to have been found as yet in plants, but is known as a very common splitting product of proteins. Its effect on plants is still somewhat doubtful. In the tests in this laboratory the lower concentrations in pure water were beneficial to growth, although concentrations as high as 500 parts per million slightly injured the roots of the wheat seedlings.

NEURINE.

Neurine is closely related to choline which has been found in soil. Neurine differs from choline in having one molecule of water less in its composition, and belongs to the class of bodies known as ptomaines or toxines. Neurine is in all probability formed from choline or from its mother substance lecithin, by the life process of certain microorganisms, but has not yet been found in soil or in plants as such.

PLATE IX.



EFFECT OF NITRATE ON THE HARMFUL ACTION OF GUANIDINE.

[Cultures P to K, no nitrate; the nitrate content increases up to N.]

U

Neurine was tested in water cultures with wheat seedlings. A concentration of 6 parts per million stimulated the growth in harmony with low concentrations of toxic compounds, but the plants were already greatly injured in a solution containing 25 parts per million, and a solution of 250 parts per million killed the seedlings in a few days. When the neurine was neutralized with acetic acid, the same effects were obtained. It is thus evident that neurine is far more toxic than the related choline.

BETAINE.

Betaine, or oxyneurine, is closely related to both choline and neurine. It is found widely distributed in seeds and plants and can be derived artificially from choline by oxidation, with loss of water. In contrast with the toxic neurine, this oxyneurine was shown to be distinctly beneficial to growth in the experiments made in this laboratory. The concentrations used were from 5 to 1,000 parts per million and all showed a distinct beneficial effect. It is classed by Loew among the compounds serving as a good source of carbon for bacteria and lower forms of plant life.

SKATOL.

Skatol is a common product of putrefaction of protein materials and is known to be the product of the activities of certain bacteria. In water solutions skatol proved to be somewhat toxic to wheat seedlings. A concentration of 200 parts per million was sufficient to kill the seedlings in nine days, and in the same time a concentration of 50 parts per million was injurious, the roots being more injured than the tops, although all of the cultures showed a decrease in the weight of the tops.

PYRIDINE.

In the experiments with wheat seedlings it was found that pyridine, although not sufficiently toxic at a concentration of 1,000 parts per million to kill wheat plants in nine days, was nevertheless very injurious, especially to the green parts of the plants. In a concentration of as low as 50 parts per million the growth of the tops was inhibited and the leaf tips turned brown. In the lower concentrations there was no stimulation of growth.

In Lutz's experiments with corn and cucurbita the pyridine was likewise found to be toxic.

PICOLINE.

Picoline, or methyl pyridine, was toxic to wheat plants, but only killed in the concentrations of 1,000 parts per million, and did not cause injury below 500 parts per million. The injury seemed to be manifested by the tops more than by the roots, thus resembling the action of pyridine.

PIPERIDINE.

Solutions of piperidine in pure water killed and injured the wheat seedlings at a lower concentration than either pyridine or picoline. Death occurred in solutions of 250 parts per million.

When piperidine was neutralized with acetic acid it proved to be more toxic than the alkaline piperidine itself, causing death even at 100 parts per million. Piperidine seems to injure the roots more seriously than the tops.

QUINOLINE.

Quinoline in aqueous solution was toxic to wheat seedlings, and killed at a concentration of 500 parts per million. So low a concentration as 5 parts per million affected them injuriously in six days. None of the lower concentrations caused stimulation of growth.

ALLOXAN.

Alloxan has not been reported as occurring in plants, although it is related to convicine obtained from the seeds of Vicia species and from beet juice.

In the tests with alloxan in solutions of varying concentrations in distilled water it was found that wheat seedlings were killed in the solution containing 1,000 parts per million and injured in the solution containing 100 parts per million. In the concentrations of 25 parts per million and less the compound produced a beneficial effect.

Hutchinson and Miller report an increase in dry weight and greater nitrogen content in peas grown in alloxan cultures.

UVITONIC ACID.

Uvitonic acid has not been found in soils, but has a close relationship with picoline carboxylic acid, a soil constituent. Its effect on plants was tested with wheat seedlings, using concentrations from 1 to 200 parts per million in pure distilled water. The relative growth made in these solutions is shown in Table XXXII.

TABLE XXXII.—*Effect of uvitonic acid on wheat seedlings.*

Solutions.	Relative green weight.
Control in distilled water	100
Uvitonic acid, 1 p. p. m	107
Uvitonic acid, 5 p. p. m	116
Uvitonic acid, 10 p. p. m	108
Uvitonic acid, 50 p. p. m	78
Uvitonic acid, 100 p. p. m	68
Uvitonic acid, 200 p. p. m	Dead.

The plants growing in concentrations of 200 parts per million were dead at the end of 12 days. It is evident that uvitonic acid is quite harmful, even in concentrations as low as 50 parts per million, although the lower concentrations produced stimulation in growth in harmony with many toxic substances. It is more toxic than the related soil constituent, picoline carboxylic acid.

SOLANINE.

Solanine is a constituent of potato vine, especially of the young potato sprouts. In connection with an investigation of a potato soil the effect of this compound on potato plants was tried. The method of procuring the potato seedlings was by sprouting the potato sections on the perforated disk used for sprouting the wheat seedlings, and later separating the mother potato from the young plant, leaving the stalk and roots intact, and transferring to the culture solution to be tested.[1]

Solanine, being almost insoluble, could be used in only one concentration, namely, a saturated solution, which was less than 50 parts per million. To obtain it in solution the liquid had to be boiled, and then allowed to cool, and aerated. The control, soil extract being used as nutrient solution, was treated in the same manner so as to have all conditions alike, except the presence of the solanine. For each treatment three cultures were grown. In the experiment the growth of the control in the poor soil extract was 4.60 grams, against only 1.83 grams for the solanine dissolved in this extract. For the extract from a good soil, the control was 6.82 grams and the solanine cultures 2.33 grams. The effect of the solanine in this better soil extract is shown in Plate VII, figure 2.

In another experiment conducted at a different time essentially the same results were obtained, the solanine again being dissolved by heating as before. The soil extract control was 2.72 grams and the corresponding solanine cultures 1.98 grams. The extract from another soil gave 2.88 grams and the corresponding solanine culture 1.35 grams.

The effect of the solanine in water alone was also tested. Two of the solanine plants died in this experiment and the one that survived at the end of 18 days weighed only 0.26 gram, against 1.84 for the three control plants in the distilled water.

It is evident that in all these cultures the solanine had a detrimental effect on the growth of the potato plant.

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[1] Skinner, J. J. Water Culture Method for Experimenting with Potatoes. Plant World, 9, 249 (1906).

SUMMARY.

This bulletin deals with the effect on wheat seedlings of a considerable number of the nitrogenous compounds found in soils in the investigations of this laboratory. The compounds were tested in culture solutions containing a great variety of different fertilizer combinations. Of the soil constituents tested, nucleic acid, hypoxanthine, xanthine, guanine, creatinine, creatine, histidine, and arginine are shown to be beneficial, choline moderately beneficial, and picoline carboxylic acid moderately harmful. A considerable number of related nitrogenous compounds are also included in these investigations—some were beneficial, some were harmful, and some were without noticeable effect on growth. A comprehensive table giving the action of all of these, as well as of some nonnitrogenous compounds included in earlier work of this and other laboratories, is given.

The chief interest centers in the action of the nitrogenous soil constituents, nucleic acid, hypoxanthine, xanthine, guanine, creatinine, creatine, histidine, arginine, and choline on plant growth.

All of these compounds have beneficial effects on plant growth. Plants grown in solution cultures containing only potash and phosphate show greatly increased growth when any one of these compounds is added. The effect of these compounds is less marked when nitrate is also present. It is shown, however, that under these conditions less nitrate is used by the plant. These soil compounds are, therefore, able to replace nitrate in its effect on plant growth.

The chemical control exercised in the experiments showed that no decomposition of these compounds to ammonia, nitrite, or nitrate took place.

Evidence is presented to show that the organic compounds are absorbed by plants as such, enter into the cell, and react with the protoplasm, causing effects either detrimental or beneficial, as the case may be.

The theory is presented that these protein degradation products and nucleic acid and its decomposition products are directly used in building plant protein.

Not all nitrogenous compounds are beneficial, as a considerable number show harmful effects, among them the soil constituent picoline carboxylic acid.

Guanidine is especially interesting in that it produces effects similar to those produced by plant diseases, manifesting itself by bleached spots on the leaves, which spread, cause wilting, and final collapse. The effect is accentuated by nitrate and is least observable in the total absence of nitrate.

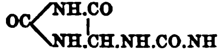
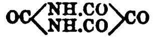
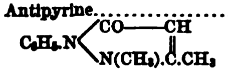
The results of these investigations show clearly that the soil contains compounds beneficial to plant life as well as compounds inimical to proper plant development. In every soil exists a balance of these two contesting influences, the good and the bad. Decrease in soil productivity, in so far as it is not due to other no less prominent factors, is due to the preponderance of that type of biochemical action which will result in the accumulation of the harmful compounds; increase in soil productivity, on the other hand, is due to favorable biochemical action resulting in the accumulation of compounds beneficial to plants. Whether one or the other predominate is due to soil conditions, drainage, composition, plant occupation, etc., which can be influenced by the operations of the farm, by tilling, by cultivation, by draining, by liming, by fertilization, and by crop rotation. All these influence the biochemical factors in soils and through them soil fertility.

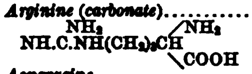
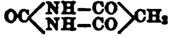
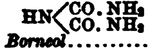
The knowledge that beneficial and harmful organic compounds exist in soils and play so prominent a part in the life processes of growing plants is of fundamental significance in soil fertility and gives a breadth of view to the subject, which, in its horizon, can not be compared with the restricted vision imposed by the purely mineral considerations.

APPENDIX.

TABLE OF ORGANIC COMPOUNDS AND THEIR EFFECT ON GROWTH.

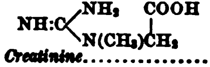
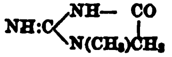
[The compounds tested in this laboratory are in italics.]

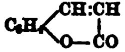
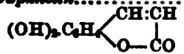
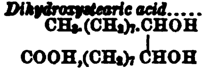
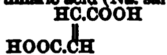
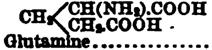
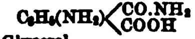
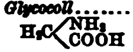
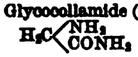
Compound tested.	Plant used.*	Effect on growth.	Method used.	Remarks.
Acetamide $CH_3.CO.NH_2$	Peas[1]	Beneficial	Water culture	Increased N. in plants.
Alanine $CH_3.CH(NH_2).COOH$	*Wheat*[2]	*Beneficial*	*Water culture*	*Harmful in concentrations of 500 p. p. m. and more.*
	Peas[1]	Doubtful	Water culture	One increase, one decrease in plant N.
	Lemna[3]	Harmful	do	
	Radish[4]	do	do	
Allantoin  $OC<\begin{matrix}NH.CO\\NH.CH.NH.CO.NH_2\end{matrix}$	*Wheat*[6]	*Slightly beneficial*	*Water culture*	
	Barley embryo[5]	Beneficial	Water culture	Increased N. in plant.
	Radish[4]	do	do	
Alloxan  $OC<\begin{matrix}NH.CO\\NH.CO\end{matrix}>CO$	*Wheat*[2]	*Harmful*	*Water culture*	*Beneficial in concentrations below 25 p. p. m.*
	Peas[1]	Beneficial	Water culture	Increased N. in plants.
Allyl alcohol $CH_2:CH.CH_2OH$	Barley[19]	Harmful	Water culture	Used in concentrations of 0.1, 0.5, and 1.0 per cent.
	Soy bean[19]	do	do	Do.
	Turnip[19]	do	do	Do.
	Onions[19]	do	do	Do.
Amygdaline $C_{20}H_{27}O_{11}N$	Radish[4]	Beneficial	Water culture	
Amyl alcohol $C_5H_{12}O$	Barley[19]	Harmful	Water culture	Used in concentrations of 0.1, 0.5, and 1.0 per cent.
	Soy bean[19]	do	do	Do.
	Turnip[19]	do	do	Do.
	Onions[19]	do	do	Do.
Aniline (sulphate) $C_6H_5.NH_2$	Cucurbita[8]	Harmful	Sand culture	
	Maize[8]	do	do	
Antipyrine  $C_6H_5.N<\begin{matrix}CO-CH\\N(CH_3).C.CH_3\end{matrix}$	Onions[7]	Harmful	Water culture	
	Celery[7]	do	do	
	Phaseolus[36]	do	do	Used in 0.5 per cent concentration.
Arbutin $C_{12}H_{16}O_7$	*Wheat*[2]	*Harmful*	*Water culture*	*Beneficial in concentrations below 25 p. p. m.*

Arginine (carbonate)  $NH.C(NH_2).NH(CH_2)_3CH\begin{matrix}NH_2\\COOH\end{matrix}$	*Wheat* [6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
Asparagine $NH_2OC.CH_2CH(NH_2).COOH$	*Wheat* [3], [6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
	Maize [9]	Beneficial	Water culture	Increased N. in plants.
	Oats [10]	do		No increased N. in plants.
	Lemna [8]	do	Water culture	Produced protein in dark from glucose.
	Barley embryo [5]	do	do	Increased N. in plants.
	Barley [11]	do	do	Do.
	Onions [11]	do	do	
	Radish [4]	do	do	Do.
Aspartic acid $HOOC.CH_2.CH(NH_2).COOH$	*Wheat* [2]	*Harmful*	*Water culture.*	*Normal below 100 p. p. m.*
	Barley embryo [5]	Beneficial	Water culture	Increased N. in plants.
	Barley [10]	Harmful		
	Radish [4]	Beneficial	Water culture	
Aspartic acid (Na. salt)	Peas [1]	Doubtful	Water culture	Increased N. in plants.
Atropine (sulphate) $C_{17}H_{23}O_3N$	Maize [8]	Harmful	Sand culture	No increased N. in plants.
	Cucurbita [8]	do	do	
	Atropa belladonna [8]	do	do	
Barbituric acid  $OC\begin{matrix}NH-CO\\NH-CO\end{matrix}CH_2$	Peas [1]	Harmful	Water culture	
Barbituric acid (+$CaCO_3$)	Peas [1]	Beneficial	Water culture	Increased N. in plants.
Benzidine $C_6H_4{}_2.NH_2{}_2$	*Wheat* [24]	*Harmful*	*Water culture*	*Oxidized by plant roots.*
Benzylamine (hydrochloride) $C_6H_5.CH_2.NH_2$	Cucumis [8]	Slightly harmful	Sand culture	No increased N. in plants.
	Ipomaea [8]	do	do	Do.
	Maize [8]	Harmful	do	Do.
Betaine $(CH_3)_3N\begin{matrix}CH_2.CO\\O\end{matrix}$	*Wheat* [2]	*Beneficial*	*Water culture*	
Betaine (hydrochloride)	Ipomaea [8]	Slightly harmful	Sand culture	No increased N. in plants.
	Maize [8]	do	do	Do.
	Barley embryo [5]	Beneficial	Water culture	Increased N. in plants.
Biuret  $HN\begin{matrix}CO.NH_2\\CO.NH_2\end{matrix}$	Barley [12]	Harmful	Water culture	
Borneol $C_{10}H_{17}OH$	*Wheat* [2]	*Harmful*	*Water culture*	
Butyl alcohol C_4H_9OH	Onions [24]	Harmful	Water culture	Used in concentrations of 0.1 per cent.
	Barley [20]	do	do	Used in concentrations of 0.1, 0.5, and 1 per cent.
	Soya bean [20]	do	do	Do.
	Turnip [20]	do	do	Do.
	Onions [20]	do	do	Do.

* The reference numbers in this column are to the list given at the end of this bulletin (p. 83), in which author, title of paper, and journal are given.

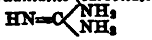
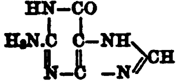
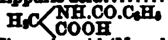
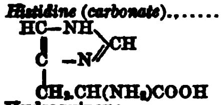
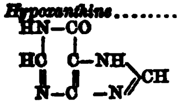
Table of organic compounds and their effect on growth—Continued.

Compound tested.	Plant used.*	Effect on growth.	Method used.	Remarks.
Butyl alcohol (iso)	Onions[34]	Harmful	Water culture	Used in concentrations of 0.1 per cent.
	Barley[19]	do	do	Used in concentrations of 0.1, 0.5, and 1 per cent.
	Soya bean[19]	do	do	Do.
	Turnip[19]	do	do	Do.
	Onions[19]	do	do	Do.
Butyl alcohol (tertiary)	Barley[19]	Harmful	Water culture	Used in concentrations of 0.1, 0.5, and 1.0 per cent.
	Soya bean[19]	Doubtful	do	Do.
	Turnip[19]	Harmful	do	Do.
	Onions[19]	Doubtful	do	Do.
Butyric amides $C_3H_7.CO.NH_2$	Higher plants[12]	Harmful	Soil and water culture	
Caffeine $C_8H_{10}O_2N_4$	Onions[7]	Harmful	Water culture	
	Celery[7]	do	do	
	Maize[8]	do	Sand culture	
	Cucurbita[8]	do	do	
	Radish[4]	do	Water culture	
Caffeine (hydrochloride)	Maize[8]	Slightly harmful	Sand culture	No increased N. in plants.
	Cucurbita[8]	do	do	Do.
	Helianthus[8]	do	do	Do.
Camphor $C_{10}H_{16}O$	*Wheat*[2]	*Harmful*	*Water culture*	
Carbamic acid (methyl salt) $OH.CO.NH_2$	Peas[1]	Harmful	Water culture	No increased N. in plants.
Choline $(CH_3)_3N\langle{}^{CH_2CH_2OH}_{OH}$	*Wheat*[2, 6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate. High concentrations injurious.*
	Barley embryo[5]	Beneficial	Water culture	Increased N. in plants.
Cinnamic acid $C_6H_5.CH:CH.COOH$	*Wheat*[2]	*Harmful*	*Water culture*	
Cinnamic acid (*Na salt*)	*Wheat*[2]	*Harmful*	*Water culture*	*Roots stimulated in lower concentrations.*
Cocaine (hydrochloride) $C_{17}H_{21}O_4N$	Helianthus[8]	Harmful	Sand culture	No increased N. in plants.
	Cucurbita[8]	do	do	Do.
	Maize[8]	do	do	Do.
Creatine $NH:C\langle{}^{NH_2\quad COOH}_{N(CH_3)CH_2}$	*Wheat*[14, 6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
	Higher plants[15]	Beneficial	Water culture	
Creatinine $NH:C\langle{}^{NH-\quad CO}_{N(CH_3)CH_2}$	*Wheat*[14, 6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*

Cumarin  $C_6H_4\left\langle\begin{matrix}CH:CH\\ O-CO\end{matrix}\right.$	*Wheat* 2, 16	*Harmful*	*Soil and water culture*	*Decreased absorption of nutrients; peculiarly stunted tops.*
	Corn 17	*do*	*do*	
Cyanuric acid $C_3N_3(OH)_3$	Peas 1	Doubtful	Water culture	
Daphnetin  $(OH)_2.C_6H_2\left\langle\begin{matrix}CH:CH\\ O-CO\end{matrix}\right.$	*Wheat* 2	*Harmful*	*Water culture*	
Dihydroxystearic acid  $\begin{matrix}CH_3.(CH_2)_7.CHOH\\ \vert\\ COOH,(CH_2)_7\ CHOH\end{matrix}$	*Wheat* 2, 30	*Harmful*	*Water culture*	*Decreased absorption of nutrients.*
Diphenylamine (hydrochloride) $C_6H_5.NH.C_6H_5$	Cucurbita 8	Harmful	Sand culture	
	Maize 8	do	do	
Esculin $C_{15}H_{16}O_9$	*Wheat* 2,24	*Harmful*	*Water culture*	*Oxidized by plant roots.*
Ethyl alcohol C_2H_5OH	Onions 24	Beneficial	Water culture	Used in concentrations of 0.1 per cent.
	Barley 19	Doubtful	do	Used in concentrations of 0.1, 0.5, and 1 per cent.
	Soy bean 19	do	do	Do.
	Turnip 19	do	do	Do.
	Onions 19	do	do	Do.
Formamide $H.CO.NH_2$	Peas 1	Beneficial	Water culture	Increased N. in plants.
Fumaric acid (Na. salt)  $\begin{matrix}HC.COOH\\ \Vert\\ HOOC.CH\end{matrix}$	Barley 22	No effect	Water culture	Germination test.
	Radish 22	Slightly harmful	do	
	Tree branches 22	Harmful	do	
Gluconic acid $CH_2OH.(CHOH)_4COOH$	*Wheat* 17	*No effect*	*Water culture*	
Gluconic acid (Ca salt)	*Wheat* 17	*No effect*	*Water culture*	
Glutaminic acid  $CH_2\left\langle\begin{matrix}CH(NH_2).COOH\\ CH_2.COOH\end{matrix}\right.$	Barley embryo 5	Beneficial	Water culture	
Glutamine  $C_3H_5(NH_2)\left\langle\begin{matrix}CO.NH_2\\ COOH\end{matrix}\right.$	Beans 8	Beneficial	Water culture	
Glycerol $CH_2OH.CHOH.CH_2OH$	Soy bean 21	Beneficial	Water culture	
Glycocoll  $H_2C\left\langle\begin{matrix}NH_2\\ COOH\end{matrix}\right.$	*Wheat* 2	*Beneficial*	*Water culture*	*Roots injured at a high concentration.*
	Peas 1	Doubtful	Water culture	
	Lemna 3	Slightly harmful	do	
	Radish 4	Beneficial	do	
Glycocollamide (hydrochloride)  $H_2C\left\langle\begin{matrix}NH_2\\ CONH_2\end{matrix}\right.$	Cnicus 8	Slightly harmful	Sand culture	Retarded germination.
	Cucumis 8	do	do	No increased N. in plants.

* The reference numbers in this column are to the list given at the end of this bulletin (p. 83), in which author, title of paper, and journal are given.

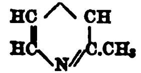
Table of organic compounds and their effect on growth—Continued.

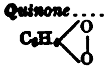
Compound tested.	Plant used.*	Effect on growth.	Method used.	Remarks.
Guanidine (carbonate)  $HN{=}C\begin{smallmatrix}NH_2\\NH_2\end{smallmatrix}$	*Wheat* [6,3] *Corn* [6] *Cow peas* [6] *Potatoes* [6]	*Harmful* *do.* *do.* *do.*	*Soil and water culture* *Water culture* *do* *do*	*Produces bleached spots.*
Guanidine (hydrochloride)	Peas [1] Barley [13]	Doubtful Harmful	Water culture do	
Guanine 	*Wheat* [3]	*Beneficial*	*Water culture*	
Hexamethylene tetramine $(CH_2)_6N_4$	Peas [1]	Harmful	Water culture	
Hippuric acid  $H_2C\begin{smallmatrix}NH.CO.C_6H_5\\COOH\end{smallmatrix}$	Barley [10]	Slightly harmful		No increased N. in plants.
Hippuric acid (Na salt)	Barley [22] Oats [23] Peas [1] Radish [4]	Slightly harmful do. do. do.	Water culture do do do	 No increased N. in plants.
Histidine (carbonate) 	*Wheat* [6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
Hydroquinone $C_6H_4(OH)_2$	Wheat [28] Plum tree twigs [28] Peach tree twigs [28] Trifolium [28] Photina [28] Rhododendron [28] Soy bean [28]	Harmful do. do. do. do. do. do.	Water culture do do do do do do	
Hypoxanthine 	*Wheat* [6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
Lactic acid $CH_3CHOH.COOH$	Phaseolus [26]	Harmful	Water culture	Used in 0.5 per cent concentration.
Lecithin	Barley [20]	Beneficial	Soil culture	Tested under acid and alkaline conditions.

Legumin	Radish [4]	Beneficial	Water culture	Increased N. in plants.
Leucine $CH_3.(CH_2)_3CH(NH_2).COOH$	*Wheat* [2,6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
	Radish [4]	Beneficial	Water culture	
	Barley embryo [5]	Harmful	do	Increased N. in plants.
	Cucumis vulg. [28]	Beneficial	Water cultures in contact with pebbles.	Do.
	Ipomaea [8]		Sand culture	No increased N. in plants.
	Lemna [3]	Doubtful	Water culture	Do.
	Barley [10]	Slightly harmful		Increased N. in plants.
Malic acid $\begin{array}{l}CH_2.COOH\\ \mid\\ CH(OH).COOH\end{array}$	Phaseolus [36]	Harmful	Water culture	Used in 0.5 per cent concentration.
Maleic acid (Na salt) $\begin{array}{l}HC.COOH\\ \parallel\\ HC.COOH\end{array}$	Barley [33]	Harmful	Water culture	
	Radish [33]	Harmful	Water culture	Germination test.
	Tree branches [33]	do	do	
Methyl alcohol CH_3OH	Onions [34]	Beneficial	Water culture	Used in concentrations of 0.1 per cent.
	Barley [19]	Doubtful	do	Used in concentrations of 0.1, 0.5, and 1.0 per cent.
	Soy bean [19]	do	do	Do.
	Turnip [19]	do	do	Do.
	Onions [19]	do	do	Do.
Morphine (hydrochloride) $C_{17}H_{19}O_3N$	Maize [8]	Harmful	Sand culture	No increased N. in plants.
	Helianthus [8]	do	do	Do.
	Cucurbita [8]	do	do	Do.
Mucin	*Wheat* [2]	*Harmful*	*Water culture*	
Myronic acid (K. salt) $C_{10}H_{19}O_{10}NS_2$	Radish [4]	Harmful	Sand culture	
Naphthylamine $C_{10}H_7.NH_2$	*Wheat* [24]	*Harmful*	*Water culture*	*Oxidized by plant roots to the purple oxynaphtylamine.*
Naphthylamine (hydrochloride)	Maize [8]	Harmful	Sand culture	
	Cucurbita [8]	do	do	
Neurine $(CH_3)_3N\begin{array}{l}\diagup CH{:}CH_2\\ \diagdown OH\end{array}$	*Wheat* [2]	*Harmful*	*Water culture*	*Plants died in concentrations of 250 p. p. m.*
Neurine (neutralized)	*Wheat*	*Harmful*	*Water culture*	*Plants died in concentration of 250 p. p. m.*
Nicotine $C_{10}H_{14}N_2$	Tobacco plants [35]	Beneficial	Water culture	
Nucleic acid (+ $CaCO_3$)	*Wheat* [6]	*Beneficial*	*Water culture*	*Plants absorb less nitrate.*
Nuclein	Barley [30]	Beneficial	Soil culture	Tested under alkaline and acid conditions.

* The reference numbers in this column are to the list given at the end of this bulletin (p. 83), in which author, title of paper, and journal are given.

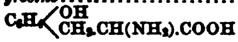
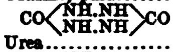
Table of organic compounds and their effect on growth—Continued.

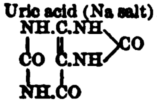
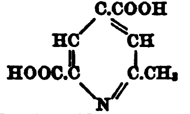
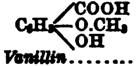
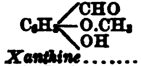
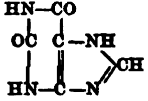
Compound tested.	Plant used.*	Effect on growth.	Method used.	Remarks.
Oxamide $CONH_2$ | $CONH_2$	Peas [1]	Doubtful	Water culture	
Peptone	Peas [1]	Doubtful	Water culture	
Phenylalanine $C_6H_5.CH_2.CH(NH_2).COOH$	Barley embryo [5]	Harmful	Water culture	
Phloroglucin $C_6H_3(OH)_3$	*Wheat* [2]	*Harmful*	*Water culture*	*Beneficial in low concentrations, 1 p. p. m.*
	Soy bean [23]	Harmful	Water culture	
	Wheat [23]	do	do	
Phytin	*Wheat* [18]	*Beneficial*	*Water culture*	
	Barley [20]	Beneficial	Soil and sand culture	Tested under alkaline and acid conditions.
	Lupine [23]	do	Water culture	
Picoline $C_5H_4N.CH_3$	*Wheat* [3]	*Harmful*	*Water culture*	*No effect in low concentrations, below 100 p. p. m.*
Picoline carboxylic acid 	*Wheat* [20,4]	*Harmful*	*Water culture*	
Piperidine $C_5H_{11}N$	*Wheat* [2]	*Harmful*	*Water culture*	
Piperidine (*neutralized*)	*Wheat* [2]	*Harmful*	*Water culture*	*Beneficial in low concentrations, 1 p. p. m.*
Piperidine (hydrochloride)	Cucumis [8]	Harmful	Sand culture	
Piperonal (*heliotropine*) $(CHO).C_6H_3{<}\genfrac{}{}{0pt}{}{O}{O}{>}CH_2$	*Wheat* [2]	*Harmful*	*Water culture*	
Propionic amides $C_2H_5.CO.NH_2$	Higher plants [12]	Harmful	Soil and water culture	
Propionitrile $C_2H_5.CN$	Peas [1]		Water culture	Increased N. in plants.
Propyl alcohol C_3H_7OH	Barley [19]	Harmful	Water culture	Used in concentrations of 0.1, 0.5, and 1.0 per cent.
	Soy bean [19]	Doubtful	do	Do.
	Turnip [19]	Harmful	do	Do.
	Onions [19]	Doubtful	do	Do.
Propyl alcohol (iso)	Barley [19]	Harmful	Water culture	Used in concentrations of 0.1, 0.5, and 1.0 per cent.
	Soy bean [19]	Doubtful	do	Do.
	Turnip [19]	Harmful	do	Do.
	Onions [19]	Doubtful	do	Do.

Pyridine	*Wheat* [2]	*Harmful*	*Water culture*	
C_5H_5N				
Pyridine (hydrochloride)	Cucurbita [8]	Harmful	Sand culture	
	Maize [8]	do	do	
Pyrocatechin	*Wheat* [2]	*Harmful*	*Water culture*	*Beneficial in low concentrations, 25 p. p. m.*
$C_6H_4(OH)_2$				
Pyrogallol	*Wheat* [28]	*Beneficial*	*Water culture*	*Used in concentrations of 1 to 10 p. p. m.*
$C_6H_3(OH)_3$	*Cow peas* [36]	*do*	*Soil culture*	*Applied, 50 lbs. per acre; five-year test in field.*
	Corn [36]	*do*	*do*	*Do.*
	Potatoes [36]	*Slightly beneficial*	*do*	*Do.*
	Clover [36]	*Slightly harmful*	*do*	*Do.*
	Timothy [36]	*do*	*do*	*Do.*
Pyrogallol	*Rye* [36]	*Harmful*	*do*	*Do.*
	Wheat [36]	*Slightly harmful*	*do*	*Do.*
	Red top and timothy [30]	Slightly beneficial	Soil culture	Used at rate of 2,000 lbs. per acre in field test.
	Soy bean [28]	Harmful	Water culture	Used in concentrations of 1 per cent.
	Wheat [28]	do	do	Do.
	Plum-tree twigs [28]	do	do	Do.
	Peach-tree twigs [28]	do	do	Do.
	Trifolium [28]	do	do	Do.
	Photina [28]	do	do	Do.
	Rhododendron [28]	do	do	Do.
	Barley [30]	do	Soil culture	Used at rate of 2,000 lbs. per acre. Soil was treated and grew a crop of grass in field, when soil was potted for barley.
Pyrogallol (limed)	Red top and timothy [30]	Beneficial	Soil culture	Used at rate of 2,000 lbs. per acre in field test.
	Barley [30]	Slightly beneficial	do	Used at rate of 2,000 lbs. per acre. Soil was treated and grew a crop of grass in field when soil was potted for barley.
Pyrogallol (neutralized)	*Wheat* [28]	*Beneficial*	*Water culture*	*Used in concentrations of 100 p. p. m.*
Quinic acid	*Wheat* [2]	*Harmful*	*Water culture*	
$C_6H_7(OH)_4.COOH$				
Quinine (hydrochloride)	Helianthus [8]	Harmful	Sand culture	No increased N. in plant.
$C_{20}H_{24}O_2N_2$	Cucurbita [8]	do	do	Do.
	Maize [8]	do	do	Do.
Quinoline	*Wheat* [2]	*Harmful*	*Water culture*	
C_9H_7N				
Quinone	*Wheat* [2, 16]	*Harmful*	*Water culture*	*Decreased absorption of nutrients. Tall slender plants.*
 $C_6H_4\langle O_2$	Soy bean [28]	Harmful	Water culture	
	Wheat [28]	do	do	
	Radish [28]	do	do	
	Plum-tree twigs [28]	do	do	
	Peach-tree twigs [28]	do	do	
	Trifolium [28]	do	do	
	Photina [28]	do	do	
	Rhododendron [28]	do	do	

* The reference numbers in this column are to the list given at the end of this bulletin (p. 83), in which author, title of paper, and journal are given.

Table of organic compounds and their effect on growth—Continued.

Compound tested.	Plant used.*	Effect on growth.	Method used.	Remarks.
Resorcin $C_6H_4(OH)_2$	Trifolium [28]	Harmful	Water culture	
	Photina [28]	do	do	
	Rhododendron [28]	do	do	
	Plum-tree twigs [28]	do	do	
	Peach-tree twigs [28]	do	do	
Ricin	*Wheat* [2]	*Harmful*	*Water culture*	
Sarcine	Radish [4]	Slightly beneficial	Water culture	
Skatol $C_6H_4\left\langle\begin{matrix}C.CH_3\\NH\end{matrix}\right\rangle CH$	*Wheat* [2]	*Harmful*	*Water culture*	
Solanine $C_{52}H_{93}O_{18}N$	*Potatoes* [6]	*Harmful*	*Water culture*	
Tetranitromethane $C(NO_2)_4$.	Peas [1]	Harmful	Water culture	
Theobromine $C_7H_8O_2N_4$	Radish [4]	Harmful	Water culture	
Turpentine $C_{10}H_{16}$	*Wheat* [2]	*Harmful*	*Water culture*	
Tyrosine $C_6H_4\left\langle\begin{matrix}OH\\CH_2.CH(NH_2).COOH\end{matrix}\right.$	*Wheat*	*Harmful*	*Water culture*	
	Barley embryo [6]	Harmful	Water culture	
	Cucumis vulg. [22]	Beneficial	Water culture in contact with pebbles.	Increased N. in plants.
	Cucumis melo. [8]	Harmful	Sand culture	No increased N. in plants.
	Radish [4]	do	Water culture	
Urazine, para $CO\left\langle\begin{matrix}NH.NH\\NH.NH\end{matrix}\right\rangle CO$	Peas [1]	Harmful	Water culture	
Urea $CO\left\langle\begin{matrix}NH_2\\NH_2\end{matrix}\right.$	Higher plants [12]	Harmful	Soil and water culture	
	Barley [10]	do		
	Lupinus [26]	Beneficial	Water culture	Produced asparagine.
	Potatoes [26]	do	do	Do.
	Holesia hisp. [26]	do	do	Do.
	Wheat [26]	do	do	Do.
	Barley [26]	No effect	do	Did not produce asparagine.
	Oats [26]	Beneficial	do	Increased N. in plant.
	Lemna [3]	do	do	
	Onions [27]	Harmful	do	Beneficial in small amounts.
	Radish [4]	Beneficial	do	

Uric acid (Na salt) 	Oats [22]	Beneficial	Water culture	
	Barley [22]		do	Increased N. in plant.
	Radish [4]	Beneficial	do	
Uvitonic acid 	*Wheat* [20]	*Harmful*	*Water culture*	
Valeric amides $C_4H_9.CO.NH_2$	Higher plants [13]	Harmful	Soil and water culture	
Vanillic acid 	*Wheat* [2]	*Harmful*	*Water culture*	*Beneficial in concentrations below 25 p. p. m.*
Vanillin 	*Wheat* [2, 16]	*Harmful*	*Water culture*	*Oxidized by plant roots.*
Xanthine 	*Wheat* [2]	*Beneficial*	*Water culture*	
	Radish [4]	Beneficial	Water culture	

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* The reference numbers in this column are to the list given at the end of this bulletin (p. 83), in which author, title of paper, and journal are given.

Notes on the occurrence of the organic compounds tested, together with their chemical relationship from the point of view of their probable appearance in soils:

Alanine is related to phenylalanine and is a common splitting product of proteins, being derived from peas, soy beans, and squash and pumpkin seeds.

Allantoin occurs in some animal fluids and has been found in the young leaves of the Plane tree, in sprouts of Acer species, and in the bark of the horse chestnut, in beet juice, and extract of malt.

Alloxan is closely related chemically to convicine, which is found in beets and beans.

Amygdaline occurs in bitter almonds and in the leaves, flowers, barks, and seeds of many other plants.

Arbutin is widely distributed among plants, especially in the Ericaceæ or heath family.

Arginine has been found in soils, in the seeds of *Lupinus augustifolius*, *Lupinus albus*, *L. luteus*, and *Robinia pseudacacia*, and many other plants. A common decomposition product of protein.

Asparagine occurs in young shoots of asparagus and a large number of other plants of many different families.

Aspartic acid has been found in young sugar cane and the molasses of sugar beets, and exists in seedlings of beans and pumpkins.

Atropine is present in the berry of *Atropa belladonna*, in the thorn apple, and in the fruit of *Datura stramonium*.

Betaine occurs in the juice of sugar beets, is closely related to choline and neurine, occurs widely distributed in seeds and plants.

Biuret is formed from urea by heat.

Borneol occurs in needles of pines, firs, spruces, hemlock, and golden rod, thyme, and other plants.

Butyl alcohol is formed from glycerol by the action of certain bacteria in cow manure.

Caffeine occurs in the leaves and beans of the coffee tree, in tea, in cocoa, in cola nuts, etc. It is related chemically to xanthine.

Camphor, the ketone of borneol, is secreted by different plants, found in the wood of cinnamomum, sassafras leaves, cinnamon roots, spike, rosemary, basilicum roots, etc.

Choline is a derivative of lecithin and is found in many seeds and growing plants. It has been found in soils.

Cinnamic acid is found in resin balsams, storax, tolu, etc., and occurs in the decomposition products of the associated alkaloids of cocaine.

Cocaine is present in cocoa leaves.

Creatinine has been found in soils, and in the bran, seeds, straw, and seedlings of wheat; rye and clover seeds, cowpea plants and potato tubers. It is a constituent of animal flesh, barnyard manure, and urine.

Creatine is closely related chemically to creatinine.

Cumarin has been reported in grasses, clover, beets, in various dicotyledons and a number of other plants. It can be formed from carbohydrates by the action of certain mold fungi.

Cyanuric acid is a decomposition product of biuret when heated.

Cystein is closely related chemically to cystin, which is a constant and abundant dissociation product of most albumins.

Daphnetin occurs in various species of Daphne and is related to cumarin.

Dihydroxystearic acid is widely distributed in soils, especially in soils of low productivity.

Esculin and esculetin, its glucoside, have been found in the bark of the chestnut tree and other plants.

Fumaric acid occurs free in many plants, in moss, in *Fumaria officinalis*, and in some fungi.

Gluconic acid is formed from glucose by *Bacterium savastanoi*.

Glutamic acid occurs in the seeds of wheat.

Glutamine occurs in lemons, in cucumbers, and other plants.

Glycocoll is a protein degradation product found where decomposition is occurring, has been derived from the protein of peas, soy beans, squash, pumpkin seed, and others.

Guanidine is a constituent of many plants and can be made from arginine by oxidation ; arginine is a protein decomposition product found in plants and in soils.

Guanine is a constituent of guano; has been found in the seeds of vetch, alfalfa, clover, and gourd, in germinating barley, in sugar beet, and sugar cane. It has been found in soil.

Hippuric acid occurs in animal urine, especially that of the horse and elephant.

Histidine occurs in many plants and is a constant decomposition product of protein. It has been found in soil.

Hydroquinone occurs in *Protea mellifera;* it is chemically related to quinone. It is obtained from quinone by reduction.

Hypoxanthine has been found in soils and is a constituent of potatoes, and the juice of sugar beets. It is a decomposition product of nucleic acid and is closely related to xanthine.

Lecithins are closely related to the fats in constitution, and are found in vegetable tissues.

Legumin occurs in the seeds of a number of plants, especially the white lupine, pears, etc.

Leucine is a decomposition product of protein. It occurs in vetches, lupine, gourd, molasses of the sugar beet, potatoes, corn, etc.

Lactic acid is produced from protein material by widely distributed bacteria.

Malic acid occurs free and in the form of salts in many plant juices. It is found in unripe apples, in grapes, gooseberries, in mountain ash berries, and in *Berberis vulgaris*.

Mucin has been isolated from various animal tissues and from the yams, *Dioscorea japonica* and *D. batatas*.

Myronic acid occurs in mustard and other seeds.

Neurine is a decomposition product of lecithins. Some proteins, when decomposed by bacterial growth, yield neurine.

Nicotine occurs in the tobacco plant.

Nucleic acid has been found in soils and is widely distributed in plants. Yields xanthine bases on decomposition.

Nuclein is a compound of protein and nucleic acid; yields xanthine bases when decomposed.

Peptone is a protein product and also occurs in the seeds, stems, and leaves of a variety of plants.

Phenylalanine occurs in the seeds of *Lupinus albus* and *L. luteus*, in peas, soy beans, squash and pumpkin seeds.

Phloroglucin is not found as such in plants but may be derived from several aromatic plant constituents.

Phytin occurs in rice hulls, wheat bran, and other plants.

Picoline is obtained in the decomposition of several of the alkaloids.

Picoline carboxylic acid has been found to occur in soils.

Piperidine occurs in the pepper plant and forms the nucleus of many alkaloids.

Piperonal (heliotropine) is found in the flowers of *Nigritella suaveolens*.

Pyridine is obtained from coal tar, and may also be obtained from nicotine, sparteine, and cinchonine. It is the nucleus of many of the alkaloids.

Pyrocatechin occurs in leaves and berries of *Ampelopsis quinquefolia*, in the sap of *Mimosa catechu* and sugar beets, and in several species of willow.

Quinine occurs in the bark of calisaya and other trees of the Cinchona families.

Quinolin forms the nucleus of many alkaloids found in plants belonging to the families Rubiaceæ and Loganiaceæ.

Quinone has been shown to form from proteins by the action of a certain soil fungus, *Streptithrix chromogena*, and in the decomposition of straw.

Ricin is the poisonous (to animal) principle of the castor-oil plant (*Ricinus cummunis*), and occurs in the castor bean.

Skatol is a common product of putrification of proteins and is a common product of the activities of some varieties of bacteria. It has been found in the wood of the Javanese tree (*Altis reticuflosa*).

Theobromine occurs in the cocoa bean and is chemically related to xanthine.

Turpentine is present in many plants, notably the coniferous trees.

Tyrosine is an important decomposition product of proteins. It exists as such in plants and fungus and is widely distributed.

Urea occurs in the excreta of animals and would be present in stable and barnyard manures.

Uric acid is related chemically to urea.

Uvitonic acid is closely related chemically to picoline carboxylic acid, which is a soil constituent.

Vanillic acid may be formed by oxidation from vanillin.

Vanillin forms readily from a glucoside, and has been reported in oats, white lupine, asparagus shoots, raw beet sugar, etc., in addition to its occurrence in the vanilla bean.

Xanthine, which is closely related to guanine, has been found in a number of plants. It has also been found to occur in soils.

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN NO. 88.
MILTON WHITNEY, Chief.

SOME ORGANIC SOIL CONSTITUENTS.

BY

EDMUND C. SHOREY,
SCIENTIST IN SOIL FERTILITY INVESTIGATIONS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., July 16, 1912.

Sir: I have the honor to transmit herewith the manuscript of a scientific paper entitled "Some Organic Soil Constituents," by Dr. Edmund C. Shorey, of this bureau. This article is the result of an extensive study of a number of soils and reports the further isolation and identification of 14 definite organic compounds from soils, showing the great complexity of the organic matter, and makes clear its chemical nature and suggests their origin in the soil.

The investigation throws considerable additional light upon the questions of soil fertility, and I have, therefore, the honor to recommend that the article be published as Bulletin No. 88 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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SOME ORGANIC SOIL CONSTITUENTS.

INTRODUCTION.

A continuation of the investigation into the nature of the organic matter of soils, begun by the Bureau of Soils a few years ago and reported in previous bulletins,[1] has resulted in considerable additional information regarding the chemical identity of the compounds in this complex mixture.

It is the purpose of the present bulletin to report the isolation of a number of organic compounds found in soil organic matter not included in previous publications of this laboratory. The methods by which these compounds have been isolated will be described, their properties noted, and their possible origin considered.

In the reports of previous work along this line the importance of some definite chemical knowledge of the nature of the organic matter of soil, from the practical as well as the purely scientific standpoint, has been so fully discussed that it seems necessary here but to mention that all the evidence regarding the nature of this material indicates that it is of very complex composition; that nearly all classes of organic chemical compounds may be found in it; and that these compounds include some that modify the physical condition of the soil or determine the nature of the microorganisms growing therein, as well as those that may be directly harmful or beneficial to crops

In the continuation of this work, the same general methods described in previous reports have been used, either so modified as to meet the requirements of the isolation of a definite compound sought, or, in the general search for unknown compounds, so changed as to overcome difficulties presented by the particular soil under examination.

The starting point in these methods has been generally an extraction of the soil with dilute alkali, usually a 2 per cent solution of sodium hydroxide. When the solution so obtained is acidified the so-called humous bodies are precipitated, and on filtering there is obtained an acid filtrate containing, in addition to free acid and a sodium salt, a portion of the organic matter of the soil.

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[1] Bulletins Nos. 53, 74, and 83, Bu. of Soils, U. S. Dept. Agr.

All of the compounds described in this bulletin have been found in this acid filtrate and are, therefore, included in that portion of the soil organic matter soluble in cold dilute alkali and remaining in solution in part at least when this alkaline extract is acidified.

The soils examined have been for the most part samples submitted or requested because of some special problem in soil fertility. This problem may have been either a general failure of crops, or, more often, a failure of some particular crop, with the preponderance of evidence indicating unfavorable soil conditions. In some cases but a single compound was isolated from one soil and no attempt was made to study the whole of the organic matter in any one sample other than to determine the presence or absence of organic compounds such as dihydroxystearic acid, creatinine, purine bases, etc., that have been found to be rather widely distributed.

The occurrence of the compounds isolated in other soils or the distribution of these compounds in soils generally has been left for future work.

Recent improvements in the equipment of the laboratory devoted to this work have made it possible to handle much larger samples of soil than before, and the presence of compounds has in some cases been established where it would probably have been overlooked when working with smaller samples and under the limitations of the ordinary equipment.

The chief features of this equipment are a porcelain-lined kettle of 80-gallon capacity, provided with a power-driven stirrer, in which 50 pounds of soil can be treated with the solution of sodium hydroxide, and a vacuum pan in which the extract after neutralizing can be concentrated to a small volume at a comparatively low temperature. With this equipment it is possible to extract 50 pounds of soil twice, and have the final solution ready for chemical treatment concentrated to 4 or 5 gallons in three days.

ORGANIC ACIDS.

Organic acids, either as such or as salts, are present in all living vegetation. The number of such acids is large and the quantity often present is a considerable portion of the plant tissues or juices. These acids or their decomposition products become a part of the organic matter of the soil when the débris of dead vegetation is incorporated with the soil. Furthermore, organic acids are the most common products of the decay of fats, protein, and carbohydrates, and they must be formed in great variety and quantity in the course of the decomposition of plant remains in the soil.

The character of the organic acids added to the soil or formed in the soil will naturally depend on the character of the vegetation, but probably also on the character of the microorganisms in the soil and the nature of its mineral constituents.

The tendency of nearly all organic acids in the process of decay is to change ultimately into simple gaseous products such as carbon dioxide, marsh gas, ammonia, and nitrogen; but the microflora in a soil may be such that this change is not brought about; or intermediate products may be used as food by microorganisms and built up again into new complex compounds. On the other hand, the acids in plant remains or those formed in the first stages of decay may be immediately neutralized by combination with some of the mineral constituents of the soil, resulting in insoluble or little soluble salts that may resist further change.

Soils that give an acid aqueous extract are not uncommon, a condition that can mean either the presence of a free acid, an acid salt, or a neutral salt that is hydrolyzed in water solution. Although several acids have been isolated from soils, there is as yet no conclusive evidence as to the identity of the free acids, if such exist, in acid soils. There is abundance indirect evidence that there are in soils combinations of organic acids with mineral bases, but naturally when dealing with such a complex mixture of organic and mineral matter as a soil any attempt to couple up an organic acid isolated with any single mineral constituent is purely a matter of conjecture.

OXALIC ACID, $C_2H_2O_4$.

Oxalic acid was first isolated from a soil in the examination of a sample from Hood River Valley in Oregon. This soil, a dark-colored fine sandy loam, had been for some years devoted to apple growing.

The method by which oxalic acid was isolated from this soil was as follows: An alkaline extract was acidified with acetic acid and filtered from the humus precipitate, which was small in quantity. The acid filtrate was neutralized with sodium hydroxide and concentrated in a vacuum pan to about one-fourth its volume, acidified again with acetic acid, and filtered from a further slight precipitate. Lead acetate in excess was then added to the slightly acid solution, filtered, and ammonia to strong alkalinity added to the filtrate. The precipitate thus formed was filtered off, washed, and decomposed by hydrogen sulphide. The filtrate from lead sulphide was evaporated to dryness and the dry residue extracted with ether, the ether evaporated, and the residue taken up with water and filtered. The clear, somewhat colored solution was made alkaline with ammonia and a little calcium-chloride solution added, filtered immediately from a colored flocculent precipitate that formed, and the filtrate allowed to stand in a warm place some hours, when a white, crystalline precipitate formed. This, on examination under the microscope, presented the dumb-bell shaped crystals characteristic of calcium oxalate. These crystals were soluble in mineral acid, insoluble in acetic acid, and could be recovered again in characteristic form from acid solution by making alkaline with ammonia and heating or allowing to stand.

On evaporating a hydrochloric acid solution of this precipitate to dryness, extracting the residue with ether, crystals having the appearance, solubility, and other properties of oxalic acid were obtained on evaporation of the ether. These crystals lost water of crystallization on heating, and after drying at 100° melted at 189°. When heated with concentrated sulphuric acid, carbon dioxide and monoxide were evolved. A water solution decolorized a solution of potassium permanganate. On heating with para toluidine and washing the product with alcohol a white compound crystallizing in plates and melting at 267° was obtained. The crystalline form and melting point of this compound correspond with those of oxal-para-toluide, a compound characteristic of oxalic acid. The quantity of oxalic acid obtained from this soil by this method was small, and on the assumption that the oxalic acid might be present in the soil as calcium oxalate or as some salt little soluble and not likely to be decomposed by the short treatment with dilute alkali, recourse was had to another method to ascertain if more were present than appeared from the results obtained. The soil was leached with dilute cold hydrochloric acid, 2 to 3 per cent, and the yellow-colored extract concentrated by evaporation at a low temperature. On extracting the concentrated extract with ether a crystalline residue, having in part the appearance of oxalic acid, was obtained. This residue, when taken up with water, gave all the reactions of a solution of oxalic acid, and the quantity obtained was much greater than by the method first used. It was further found that by concentrating the acid soil extract to the point where crystallization began, allowing to cool and drying the mass on a porous plate, redissolving in water, and repeating this operation several times, a fairly pure preparation of crystallized oxalic acid could be obtained. The original extract was strongly colored with ferric chloride, and it was not possible by this method to remove the last traces of yellow tinge from the crystals of oxalic acid.

An attempt to determine the quantity of oxalic acid present in the acid extract resulted as follows: An extract made by leaching 50 grams of soil with 2 per cent hydrochloric acid until no longer colored was evaporated nearly to dryness, taken up in a little water, acidified with sulphuric acid, and heated to drive off the remaining hydrochloric acid. This solution was titrated with a standard solution of potassium permanganate and the calculation made to calcium oxalate, $CaC_2O_4.H_2O$. The mean of two closely agreeing determinations gave 0.22 per cent calcium oxalate in the air-dried soil, or assuming an acre-foot of soil to weigh 3,500,000 pounds, 7,700 pounds, or nearly 4 tons of calcium oxalate per acre-foot.

Oxalic acid has not heretofore been found in soils, and so far its presence has been noted in but one sample, but in view of its wide distribution in plants and its common occurrence as a product of the decomposition of other organic material it seems that it or its salts might be expected to be rather common constituents of soils and of mineral deposits.

As a rock constituent, oxalates are of rare occurrence, three mineral forms only having been found and described. These are whewellite, calcium oxalate,[1] humboldtine, ferrous oxalate,[2] and oxammite, ammonium oxalate.[3] These have been found in but a few locations, and there is no reason to suppose that the oxalic acid in the soil examined had its origin in the rocks from which the soil was formed. On the other hand, oxalates are very common in plants. As the acid potassium salt it is found in the oxalis family and a large number of other plants. It has also been found as a magnesium salt,[4] but the most common and widely distributed form is calcium oxalate. This salt forms the raphides found in many plants, and it is also a constituent of the aleurone grains. In some of the lower plants, such as the fungi, calcium oxalate occurs in large quantity; for instance, in *Pertusaria communis*[5] 47 per cent of the dry weight of the plant and in *Chlorangium jusuffii* more than 65 per cent is made up of this salt.

Oxalic acid is also a very common product of the decomposition of organic plant constituents of all kinds. Protein, fats, and carbohydrates by the action of certain microorganisms or by treatment with chemical reagents yield oxalic acid as one of the products of oxidation, and it seems to be a general stage in the decomposition of organic matter just prior to the final resolution into carbon dioxide. Dihydroxystearic acid, a somewhat widely distributed soil constituent, yields oxalic acid as one of the products of oxidation.

Oxalic acid then is added to soils in the vegetable débris that goes to make up the organic matter of all soils and no doubt under certain conditions results from the decomposition of more complex organic matter in the soil. At present the data are not sufficient to warrant any general statement regarding the occurrence of oxalic acid in soils. The evidence at hand, however, indicates that its presence in the quantity found in this soil is not general and the conclusion seems warranted that oxalates, when added to the soils, rapidly disappear, or if generated in soils, the conditions under which they persist are abnormal. Oxalic acid appeared in this case in the hydrochloric acid extract together with iron and calcium. There was more than enough calcium present to combine with all the oxalic acid and it would, therefore, seem probable that the oxalic acid was present in the soil as calcium oxalate.

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[4] Monteverde. Botan. Centr., 43, 329 (1890).

[5] Braconnot. An. Chem. Phys., (2) 28, 318 (1825).

For an account of the occurrence of oxalic acid in plants see Czapek, Biochemie der Pflanzen. Vol. II, pp. 417–428.

SUCCINIC ACID, $C_4H_6O_4$.

Succinic acid was first isolated from a sandy loam from California devoted to orange culture.

A neutral solution obtained by extracting this soil in the usual way with sodium hydroxide and neutralizing with sulphuric acid, concentrating and filtering, was heated to boiling and then treated with a solution of ferric chloride to which ammonia had been added until a slight permanent precipitate was formed. The precipitate separated by filtering while hot was washed with hot water and then heated with dilute ammonia, and filtered hot. The filtrate was concentrated, barium chloride added, and a slight flocculent precipitate that formed separated by filtration. Two volumes of 95 per cent alcohol were then added and the solution filtered immediately from the flocculent precipitate and the filtrate allowed to stand, when a white crystalline precipitate was formed. This under the microscope had the somewhat characteristic appearance of barium succinate. From a water solution of this preparation by treatment with hot dilute sulphuric acid until there was no further precipitation, filtering from barium sulphate, and concentrating the filtrate, crystals were obtained having the properties of succinic acid.

The identity of this compound as succinic acid was indicated by the method of preparation which is a general one for the separation of this acid from other acids often found accompanying it, and this indication was confirmed by the properties of the crystals obtained. The compound crystallized in prisms soluble in water and alcohol, but very little in ether. It melted at 185°. A neutralized solution gave a red amorphous precipitate with ferric chloride, soluble in ammonia, and from this the barium salt could be made again in the manner already described. By heating with para-toluidine and washing the reaction product with alcohol white needles melting at 255° were obtained, the crystalline form and melting point being characteristic of succintoluide.

Succinic acid, while by no means so widely distributed in plants as oxalic acid, occurs commonly enough to be considered one of the compounds generally added to soil in vegetable débris. It has been found, for instance, in *Lactuca sativa*,[1] in Vermuth,[2] and *Papaver somniferum*.[3] It has been found in thymus glands of calves;[4] in the urine of cows, goats, rabbits, and horses. It is also found in fossil resins, such as amber, which is its chief commercial source, in lignite, and in brown coal.[1]

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[1] Kohuke, berg. Jahr., 25, 443.

[2] Zurger, Ann. Chem., 48, 122 (1843).

[3] Walz, Jahr. Fortsch. Chem., 263 (1860).

[4] Gorup, Ann. Chem., 76, 369 (1846).

It is also produced by certain microorganisms in the alcoholic formation of sugar,[2] in the fermentation of calcium malate,[3] and the putrifaction of flesh.[4] By purely chemical reactions it is produced in the oxidation of fats and waxes by nitric acid.[5]

It is apparent, then, that succinic acid as an organic soil constituent might have its origin from the incorporation in the soil of resinous or lignitic material, from the incorporation of plant remains containing it, or from the decomposition of organic material. The quantity of succinic acid obtained from the soil was small and owing to contaminations that always accompanied its first separation by the method described and which could not be removed without considerable loss, no attempt was made to determine the quantity present.

Nothing is as yet known regarding its distribution in other soils. The soil from which it was isolated had received rather large applications of organic fertilizers, but whether the soil was in this way rendered abnormal in respect to the presence of succinic acid or other organic constituents is not known.

SACCHARIC ACID, $C_4H_4(OH)_4(COOH_2.)$

Saccharic acid was first found in a soil from the Mount Vernon estate, Virginia. In the course of the investigation of this soil certain reactions indicated the presence of this acid, and this was confirmed by its isolation from the soil by the following procedure:

An alkaline extract acidified with acetic acid was filtered, neutralized, and concentrated; made slightly acid and filtered again. Lead acetate was added and the precipitate removed by filtration. Ammonia was added to the filtrate, the precipitate filtered off, washed, decomposed by hydrogen sulphide, and the filtrate from lead sulphide concentrated to a small volume. This residue was treated with several volumes of 95 per cent alcohol and filtered. The alcohol was removed by evaporation and the residue taken up with water, filtered again, neutralized with ammonia, and a solution of cadmium sulphate added. The precipitate formed was filtered off, washed, and decomposed by hydrogen sulphide, and the filtrate from cadmium sulphide concentrated. This residue was treated with 95 per cent alcohol, filtered, the alcohol evaporated, taken up by water, filtered again, and concentrated. The residue so obtained was a thick sirup that dried in a dessicator to a horny mass and deliquesced in the air. It was soluble in water and alcohol in all proportions, but was little soluble in ether. A watery solution reduced ammoniacal silver nitrate solution, but did not reduce Fehling's solution. On neutralizing a watery solution with potassium carbonate and adding an excess of acetic acid, there formed on standing a crystalline precipitate of fine needles. This was rather difficultly soluble in cold water and had the appearance of the acid potassium salt of saccharic acid. The preparation of this salt furnishes an effective means of purifying the product obtained from the soil, and can best be applied in the method described by introducing it just preceding the precipitation with cadmium sulphate.

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[1] Reich, Jahr. Fortsch. Chem., **48**, 499 (1847).

[2] Pasteur, Ann. Chem., **105**, 264 (1858).

[3] Dessaignes, Ann. Chem., **70**, 102 (1849).

[4] Salkowski, Ber. deutsch. Chem., **12**, 649 (1879).

[5] Bromeis, Ann. Chem., **35**, 90 (1838); **37**, 292 (1839); Stramer, Ann. Chem., **43**, 346 (1843); Ronalds, Ann. Chem., **43**, 356 (1843); Radcliff, Ann. Chem., **43**, 351 (1843).

The identity of the compound obtained in the manner described was indicated as saccharic acid by its method of isolation, its properties, and the properties of the acid potassium salt. This identity was confirmed by comparison with pure saccharic acid prepared by the oxidation of dextrose with nitric acid and finally by analysis of the silver salt. The silver salt, prepared by neutralizing a watery solution of the acid with ammonia and precipitating with silver nitrate, gave on analysis 51.02 per cent Ag., the theoretical quantity required by the formula $Ag_2C_6H_8O_8$, being 50.94 per cent.

Saccharic acid, so far as known, does not occur in plant or animal tissues. It is formed in the laboratory by oxidation of dextrose, or of disaccharides such as sucrose or maltose, or other carbohydrates, such as starch that contain the dextrose group. It is quite possible that this oxidation may be brought about by the activity of microorganisms, although at present oxidation by chemical reagents, usually nitric acid, is the only method known for its preparation.

Material that could yield this acid by oxidation is, of course, abundant in the vegetable material added to soils, and it seems quite reasonable to look upon saccharic acid as one of the products of the oxidation of this material in the soil. The soil from which saccharic acid was isolated was acid in reaction and abnormal in several respects, but examination of several other soils indicates that saccharic acid as a soil constituent is widely distributed and probably not a compound giving the soil from Mount Vernon its abnormal character.

ACRYLIC ACID, CH_2.CH.COOH.

Acrylic acid was first isolated from the soil from the Mount Vernon estate, in which saccharic acid just described was found. A neutral concentrated extract prepared in the usual manner by extracting the soil with sodium hydroxide, neutralizing with acetic acid, concentrating, and filtering, was treated with an excess of lead subacetate. The precipitate was filtered off, well washed, and while still moist treated with dilute sulphuric acid slightly in excess of the lead in the precipitate, and filtered from the lead sulphate. The dark-colored filtrate was shaken several times with ether, the ether extracts combined and shaken with a concentrated solution of sodium bisulphite. The greater portion of the coloring matter, together with aldehyde bodies, is removed from the ether by this treatment. The ether, after separation from the bisulphite solution, was allowed to evaporate spontaneously or at a low temperature on the surface of a little water, and the watery solution remaining filtered from some resinous material. The solution so obtained was slightly colored, strongly acid in reaction, and had a very sharp acetic like odor. This acid solution had the properties of acrylic acid. It decolorized a solution of potassium permanganate, and combined directly with bromine. The bromine compound crystallized in prisms soluble in ether and melted at 64° to 65°, properties characteristic of β dibrompropionic acid, a compound obtained by the direct action of bromine on acrylic acid. The acid, when neutralized, gave a crystalline precipitate with lead acetate, the crystals being needles and soluble in alcohol, properties characteristic of the lead salt of acrylic acid.

Acrylic acid has been identified in but one soil, but since its isolation and identification it has seemed likely that an acid that had previously been isolated from several soils, but not in sufficient quantity for identification, might also have been acrylic acid. These acid separations had been obtained by three separate methods and had properties, so far as ascertained, similar to those of acrylic acid. First, distillation of the soil acidified with phosphoric acid, neutralization of the slightly acid distillate with barium hydroxide, evaporation to dryness, and treatment of the residue with enough sulphuric acid to precipitate the barium and filtration from barium sulphate; second, extraction with sodium hydroxide, making acid with sulphuric acid, filtering, shaking out the filtrate with ether, and removing the ether by evaporation; third, distillation of a white crystalline crust that sometimes forms on the surface of soils in the process of drying in the field or laboratory, with sulphuric or phosphoric acid. This crust, which often collects in considerable quantities, is evidently a mixture of salts of calcium, magnesium, and other bases. Nitric acid is usually present as well as organic acids. The quantities of acids obtained by these methods have been small. In the first method there was evidently loss of acid on concentration of the neutralized distillate, either from decomposition or hydrolysis of the barium salt. The second method yielded but traces, and the distillate obtained by the third method was so complex in composition that satisfactory identification of its constituents was not possible with the quantity obtained.

Acrylic acid is not known to occur as a natural product in animal or vegetable tissues and the methods of its preparation in the laboratory are not such as to throw any light on the manner in which it may possibly be formed in the soil. Among these methods are the oxidation of acrolein, the oxidation of allyl alcohol, and the distillation of calcium lactate.

ORGANIC BASES.

Organic bases contain nitrogen usually linked with hydrogen and may be looked upon as ammonia with one or more hydrogen atoms substituted by other groups. These substituting groups may vary from the simple methyl or ethyl of the amines to the complex groups present in the hexone bases, or a number of substituted ammonias may be grouped together in ring form as in the pyrimidine derivatives and purine bases. Where the carboxyl group enters largely into the substitution and there is but one NH_2 group the resulting compound is mainly acid in character, but when there are two or more NH_2 groups or sometimes an NH group the compound is basic.

Those that have acid characteristics like the monamino acids can usually play the part of either an acid or a base, that is, they form salts with mineral acids, and also combine with mineral bases in the same way as ordinary acids. Members of the monamino acid group have not been found in soils except as the result of the hydrolysis of the soil organic matter with boiling acid, in which case the leucine and iso-leucine obtained were probably formed by the breaking down of more complex compounds of a protein character.[1]

In a previous bulletin,[2] the isolation from soils of several organic compounds, basic in character, has been reported. These were histidine and arginine, diamino acids or hexone bases, cytosine a pyrimidine derivative, and xanthine and hypoxanthine, purine bases. Since then the presence of four other organic bases in soils has been established. These are lysine, a hexone base; adenine, a purine base; and choline and trimethylamine, substituted ammonia compounds.

LYSINE, $C_6H_{14}N_2O_2$.

Lysine has been isolated from but one soil, that from California in which succinic acid was found. The method of its isolation was a modification of that used in its separation from other diamino acids in the products of the hydrolysis of protein.[3]

An acid extract, obtained by extracting the soil with sodium hydroxide, acidifying with sulphuric acid and filtering, was treated with a solution of phosphotungstic acid in 5 per cent sulphuric acid and allowed to stand some hours. The precipitate formed was washed with dilute sulphuric acid and treated with an excess of a solution of barium hydroxide, filtered, and the excess of barium removed by carbon dioxide. Silver sulphate in slight excess was added to the filtrate from the barium carbonate and solid barium hydroxide added to saturation. This treatment removes histidine and arginine. The filtrate from the precipitate of these bases was acidified with sulphuric acid and treated with hydrogen sulphide, filtered, and treated again with phosphotungstic acid as in the first stage. The precipitate was washed and treated with barium hydroxide as before, excess of barium removed b- carbon dioxide and the filtrate concentrated to a small volume.

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[1] Robertson, Tech. Bul. No. 7. Mich. Agr. Expt. Sta. (1911).

[2] Bul. No. 74, Bureau of Soils.

[3] Kossel & Kutcher, Z. physiol. Chem., 31, 166 (1900).

The resulting sirupy solution was strongly alkaline and did not show any tendency to crystallize on standing When taken up in alcohol and an alcoholic solution of picric acid added, a precipitate was formed having the characteristic appearance, properties, and composition of lysine picrate. This precipitate, after washing with absolute alcohol and dissolving in hot water, separates on cooling in rather large prisms, or if only a small quantity is treated, in fern-like aggregates. Lysine picrate is difficultly soluble in cold water, crystallizes in characteristic form, and has the composition, carbon, 38 40 per cent; hydrogen, 4.53 per cent; nitrogen, 18.67 per cent.

Elementary analysis of the preparation from soil gave carbon, 38.28 per cent; hydrogen, 4 65 per cent; nitrogen, 18 70 per cent. Lysine picrate is the most characteristic salt of lysine and its preparation and analysis can be depended upon for identification. From the picrate, lysine hydrochloride was prepared. This salt, $C_6H_{14}N_2O_2 2HCl$, is crystalline; very little soluble in alcohol, but readily soluble in water, and crystallizes from watery solution on concentration. It melts at 192° to 193°. The compound prepared from the soil showed the same properties and melting point.

Structurally, lysine is a diamino caproic acid and is represented by the formula $CH_2NH_2(CH_2)_3CH.NH_2.COOH$. It is a product of the decomposition of protein and results from such decomposition in the case of all but a few vegetable proteins and some protamines It is not known to occur as such in any vegetable or animal tissue and is usually prepared by the acid hydrolysis of protein material such as casein or gelatine.

As a constituent of soil organic matter, it can be regarded as one of the products of the decomposition of protein material in the soil. The quantity obtained from the soil in which it was found was small. Several other soils have been examined for lysine but its presence could not be shown and it does not seem to be a common constituent of the organic matter of soils.

ADENINE, $C_5H_5N_5$.

The isolation of two of the commonly occurring purine bases, xanthine and hypoxanthine, from soils has already been recorded [1]

These have been found to be somewhat widely distributed in soils, but two others that are also common decomposition products of nucleo-proteids, guanine,[2] and adenine seem not to be so common constituents of the organic matter of soils.

Adenine was first isolated from a soil from near Redding, Conn. The method used in the isolation of adenine was in the first stages the same as used in the preparation of xanthine and hypoxanthine. An alkaline extract, to which Fehling's solution had been added, was heated to boiling and a little dextrose added. The precipitate formed was removed by filtration, washed, decomposed by hydrogen sulphide, and the filtrate from copper sulphide concentrated to a small volume. Tests of a small portion of this solution by evaporation to dryness with nitric acid, addition of alkali, and heating developed no red or pink color, showing the absence of xanthine or guanine in the solution. Another portion gave a fine red color with ferric chloride, which color was unchanged by heating, a reaction characteristic of adenine. To the main portion of the solution picric acid was then added, when there was an immediate formation of bunches of fine needles. These crystals were difficultly soluble in cold water and on recrystallization from hot water melted at 180°, which is the melting point of adenine picrate.

The compound obtained by this method was identified as a purine base by its method of isolation. The absence of xanthine and guanine being established, only hypoxanthine and adenine of the common purine bases were left to be considered. The precipitate produced by picric acid fixed the identity as adenine, since hypoxanthine picrate is quite soluble. The identity of the picrate as adenine picrate was further established by its crystalline form, solubility, and melting point.

From a portion of the original adenine solution obtained as described above several other salts were prepared. Adenine bichromate, crystallizing in six-sided plates difficultly soluble in cold water, separated on allowing a mixture of adenine and chromic acid solutions to stand several hours. On evaporating a solution of adenine with hydrochloric acid and gold chloride, the characteristic double salt separated in long orange-colored prisms. Adenine hydrochloride was obtained by evaporating the adenine solution with hydrochloric acid. It crystallized in prisms easily soluble in water. The original adenine solution, when evaporated, yielded a crystalline residue of

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[1] Bul. Nos. 74 and 80, Bureau of Soils, U. S. Dept. of Agr.

[2] Guanine has been found in heated soil by Mr. E. C. Lathrop, of this laboratory, and will be reported later.

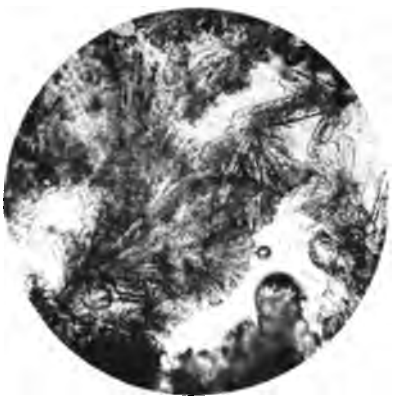

FIG 1. ACID POTASSIUM SACCHARATE.

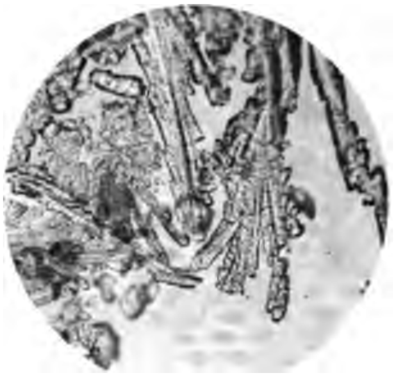

FIG. 2. SUCCINIC ACID.

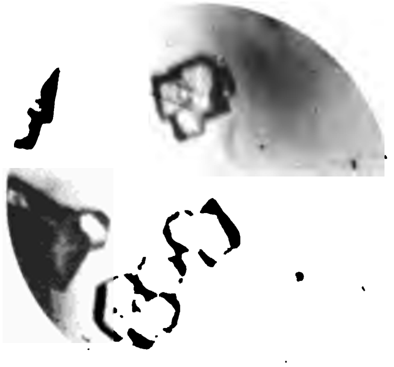

FIG. 3. CHOLINE PLATINUM CHLORIDE.

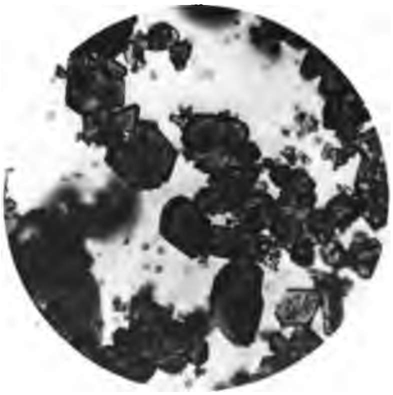

FIG. 4. TRIMETHYLAMINE PLATINUM CHLORIDE.

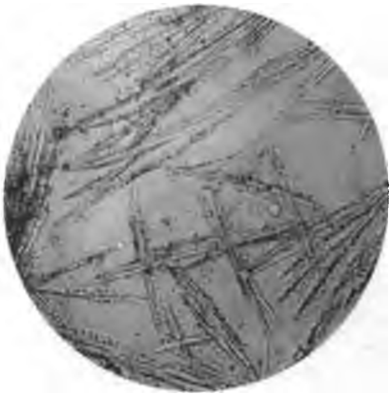

FIG. 5. TRITHIOBENZALDEHYDE.

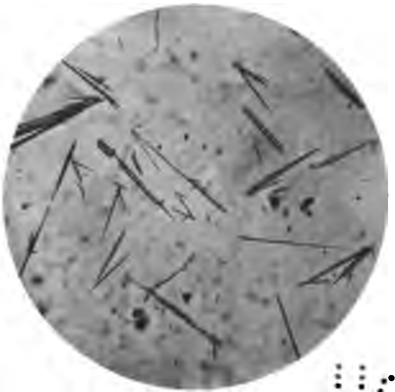

FIG. 6. LYSINE PICRATE.

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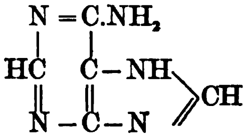
PHOTOMICROGRAPH OF ORGANIC COMPOUNDS ISOLATED FROM SOILS AND OF CHARACTERISTIC DERIVATIVES OF THESE.

HELIOTYPE CO. BOSTON

microscopic needles, soluble rather easily in water but little or not at all in alcohol or ether.

In the application of this method to soils generally the solution finally obtained would contain creatine or creatinine if present in the soil in addition to the purine bases. In this case the solution apparently was one of nearly pure adenine, no other purine bases being present, and but traces of creatinine.

Adenine structurally is 6-amino purine and is represented by the formula,



It was first prepared from the pancreatic glands and is found in all animal tissues or fluids rich in nucleated cells. . It has been found in products of the autodigestion of yeast and in several plants. It is most conveniently prepared from an extract of tea leaves.

The soil from which adenine was obtained was rather abnormal in several respects. It was sandy loam, a woodland soil, uncultivated and bearing sparse vegetation. It had been found to contain a relatively large quantity of dihydroxystearic acid. Since its isolation from this soil adenine has been obtained from other soils, but apparently is not so common a constituent as xanthine or hypoxanthine. Adenine, like the other purine bases, occurs as a decomposition product of nucleic acid, and its presence in soils may be due to the addition as such in plant or animal matter or to the decomposition of antecedent compounds in the soil.

CHOLINE, $C_5H_{15}NO_2$.

Choline, an organic basic compound represented by the structural formula $C_2H_4OH.N(CH_3)_3OH$, or hydroxy-ethyl-trimethyl ammonium hydroxide, has been isolated from a sample of Volusia silt loam from New York. The method of isolation depended on the precipitation of the compound with mercuric chloride and was carried out in the following manner: An alkaline extract of the soil was acidified with acetic acid, filtered, neutralized with sodium hydroxide, and filtered again. To the neutral filtrate lead acetate was added as long as a precipitate was formed, filtered, and excess of lead removed from the filtrate by hydrogen sulphide. The filtrate was concentrated to a similar volume, treated with several volumes of alcohol, a little hydrochloric acid added, and the material insoluble removed by filtration. To this filtrate an alcoholic solution of mercuric chloride was added and the whole allowed to stand several days. The precipitate which formed was separated, dissolved in water, the watery solution concentrated, and the crystals that separated dissolved again in water and treated with hydrogen sulphide. The filtrate from mercuric sulphide on concentration yielded crystals having the properties of choline hydrochloride.

A watery solution gave precipitates with phosphotungstic and phosphomolybdic acids, with mercuric and gold chlorides and with iodine in potassium iodide solution. The precipitate with gold chloride was soluble in hot water and alcohol. It crystallized from water solutions in small prisms and needles that melted at 239° to 240°, and on analysis was shown to contain 44.40 per cent Au., the theoretical gold content for $C_5H_{14}NO\ Cl.AuCl_3$, being 44.48 per cent. On addition of platinum chloride and concentration orange-red six-sided plates were formed, easily soluble in water but insoluble in alcohol. These melted at 230° to 233°, the melting point of choline platinum chloride being given by different authorities at 213° to 240°.

On treating this solution of choline hydrochloride with silver oxide, filtering from silver chloride, and concentrating, a sirupy liquid was obtained, strongly alkaline in reaction and having all the properties of choline. From this the hydrochloride, mercuric, gold, and platinum double salts could be obtained again in crystalline form.

The quantity of choline isolated from this soil was small and would probably have escaped detection in a general search for organic compounds. The special search for choline has not been applied to other soils and no statement can be made regarding its distribution in soils.

Choline is widely distributed in both animal and vegetable tissues and is also one of the products in the first stages of the decomposition of more complex compounds in these tissues. The presence of choline in soils may then be due either to its direct addition in organic débris or to the decomposition of more complex compounds in the soil.

TRIMETHYLAMINE, C_3H_9N.

The fishy ammoniacal odor characteristic of the monamines is sometimes observed when the soil is treated with cold dilute alkali, as in the method of extraction of the soil organic matter used throughout these researches. In the case of one soil, a salt marsh soil from Georgia, this odor was so pronounced and persistent that it was thought it might be possible to determine the identity of the amine present. For this purpose the soil was treated with sufficient water and magnesium oxide to make a thin mud strongly alkaline in reaction. This was distilled under reduced pressure, the distillate made acid with hydrochloric acid, and evaporated to dryness. In this way a quantity of crystalline material soluble in water was obtained, which, when made alkaline, had the odor of amines and ammonia, the latter predominating so strongly that it was evident that ammonium chloride made up a large proportion of the mixture. Efforts to separate the amine chlorides from ammonuim chloride by treatment with absolute alcohol, in which the latter is stated to be insoluble, resulted in but a partial separation. The alcohol soluble portion contained, after several treatments, considerable ammonia. After this partial separation of ammonuim chloride, the alcohol soluble portion, after evaporation of the alcohol, was taken up in water and this solution gave reactions characteristic of trimethylamine. When acidified with hydrochloric acid and potassium ferrocyanide added, a white crystalline precipitate quite insoluble in water was formed. The formation of this precipitate under these conditions indicated the presence of a tertiary monamine. On treatment of this acid ferrocyanide with a solution of copper sulphate, filtering, and removing sulphuric acid and excess of copper sulphate from the filtrate by the addition of a solution of barium hydroxide there was obtained a solution having a strong amine odor. On addition of platinum chloride to a solution of the mixed chlorides there was formed a precipitate in which crystals having the form of both ammonium chloroplatinate and trimethylamine chloroplatinate were observed, but it was not possible with the material available to separate the two completely enough to make further tests of the identity of the latter. Other attempts to separate completely the relatively larger amount of ammonium chloride obtained by the method used and to prepare other characteristic salts of trimethylamine or other amines failed. The evidence of the presence of trimethylamine in this soil rests first on the amine odor of the distillate obtained by distilling the soil with magnesium oxide, and second, on the precipitate of an acid ferrocyanide obtained when potassium ferrocyanide and hydrochloric acid were added to the neutralized and concentrated distillate. Third, that the amine compound could be recovered from this ferrocyanide precipitate, and fourth, on the formation of the chloroplatinate.

Trimethylamine occurs as such in both animal and vegetable products. It has been found in *Chenopodium vulvaria,*[1] *Crategus oxyacantha,*[2] and other plants, and is one of the products of the decomposition of choline just described. As a soil constituent it therefore might be the result of direct addition in plant débris or a decomposition product of some such compound as choline.

ALDEHYDES.

Compounds of an aldehyde nature seem to be a rather common constituent of soil organic matter, but up to the present the identity of one only has been established.

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[1] Dessaigues, Compt. Rend., 33, 358 (1851). [2] Wicke, Ann. Chem., 91, 121 (1854).

SALICYLIC ALDEHYDE, $C_6H_4.OH.COH$.

Salicylic aldehyde was isolated from a sample of a soil from the Mount Vernon estate, Virginia, the same soil in which saccharic acid previously described was found. It was obtained in the following manner:

The usual sodium hydroxide extract was acidified with sulphuric acid and filtered. The acid filtrate was shaken out with several portions of ether, the ether extracts combined and shaken with a concentrated aqueous solution of sodium bisulphite. The bisulphite solution was separated from the ether, strongly acidified with sulphuric acid and air blown through it to remove sulphur dioxide. This solution was then shaken with several portions of fresh ether, the ether extracts combined, and the ether removed by evaporation over a small volume of water. The solution remaining was filtered from a small quantity of resinous insoluble material, and as thus obtained was a slightly colored solution, had an aromatic odor, and the properties of a solution of salicylic aldehyde. On slow evaporation of the water there was left a yellow oil somewhat difficultly soluble in water, but very soluble in alcohol or ether. The water solution developed a pink color in fuchsine aldehyde reagent almost immediately and gave an intense violet color with ferric chloride. When treated with phenylhydrazine, a precipitate was formed, which, on recrystallization from alcohol, was in the form of yellow leaflets that melted at 143°, the characteristic form and melting point of the phenylhydrazone of salicylic aldehyde. The separation of this compound from ether solution by an aqueous solution of sodium bisulphite and the color produced with fuchsine reagent fix it as an aldehyde. The general properties of the compound and the formation of the hydrazone melting at 143° are sufficient to identify it as salicylic aldehyde.

Salicylic aldehyde occurs in several plants, in several species of *Spirea*,[1] and in *Crepis foetida*.[2]

It is also formed by the oxidation of salicin, a glucoside that occurs in many species of *Salix* and *Spirea*. Its occurrence in soil then may be due to the addition of the aldehyde itself, or bodies yielding it in vegetable remains.

UNIDENTIFIED ALDEHYDES.

Salicylic aldehyde has been isolated from but one soil, but many other soils when examined according to the method by which salicylic aldehyde was obtained yield a compound or mixture of compounds having aldehyde properties, but differing from salicylic aldehyde.

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[1] Ettling, Ann. Chem., 35, 247 (1838); Wicke, Ibid., 93, 175 (1855).

[2] Wicke, Ann. Chem., 91, 374 (1856).

Usually when the aqueous solution of this material is evaporated there is a solid residue, somewhat soluble in water, and easily soluble in alcohol and ether. The water solution gives a violet color with ferric chloride and usually gives no color with fuschine reagent unless previously boiled for a few minutes with strong hydrochloric acid. No crystals have been observed in the solid residue and it has not been possible to prepare a crystalline phenylhydrazone or other derivative. The appearance and properties of this material suggest polymerized aldehydes but the quantity obtained has been too small to establish their identity.

CARBOHYDRATES.

Carbohydrates, represented by starch, sugars, and cellulose, make up a large portion of plant tissues and material in solution in the juices of plants. The ready susceptibility of the sugars and starches to the action of enzymes and microorganisms renders it probable that these plant constituents rapidly disappear from the tissues when a plant dies and are less likely to be incorporated with the soil than other organic compounds of plants. Evidence of the occurrence of carbohydrates in soils has heretofore been confined to the demonstration of the presence of pentosans or pentose-yielding bodies,[1] and, as pointed out, the pentose sugar might have been derived from complex ligno-cellulose, from nucleic acids, or from pentose-yielding glucosides, any or all of which might be fairly resistant to decomposition.

It seems evident from examination of a large number of soils that pentose-yielding material is a constant constituent of the organic matter of soils.

Two compounds isolated from soils, mannite and rhamnose, are classed in this carbohydrate group, although the term "sugars" perhaps would be the more proper designation. Rhamnose is present in the soil as a glucoside, from which it is set free in heating with a mineral acid. Mannite, although a hexatomic alcohol, is so closely related to the sugars that it is included in this section.

MANNITE, $C_6H_{14}O_6$.

Mannite was found in the soil from the Mount Vernon estate already mentioned in connection with the isolation of saccharic and acrylic acids and salicylic aldehyde. The sodium hydroxide extract was acidified with sulphuric acid, filtered, neutralized, and concentrated. To this solution, slightly acidified with acetic acid, lead acetate was added until there was no further precipitate of lead sulphate, filtered at once, and ammonia and a little more lead acetate added to the filtrate and the whole allowed to stand 24 hours. It was found that the first treatment with sulphuric acid and filtration removed material that could not be removed by acetic acid, and that this material, unless removed, interfered greatly with the separation and purification of the final product. The precipitate formed by ammoniacal lead acetate was collected, washed, decomposed by hydrogen sulphide, and the filtrate from lead sulphide concentrated to a small volume. On cooling, crystals in the form of needles and prisms formed. These were removed from the mother liquor, dried on a porous plate, and recrystallized several times from water. The crystals thus obtained were soluble in water and alcohol but insoluble in ether. They melted at 166°, agreeing with the melting point of mannite. The water solution was optically inactive, but on the addition of borax became markedly dextro rotatory. The solution did not reduce Fehling's solution or ammoniacal silver, but did reduce a solution of silver acetate.

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[1] Bul. No. 74, Bureau of Soils, U. S. Dept. of Agr.

By treatment of the compound with concentrated hydrochloric acid and benzaldehyde, crystals were formed, difficultly soluble in acid. The compound crystallized in needles and melted at 191°, characteristic properties of mannite-tribenzacetol formed from mannite in this way.[1] The identity of the compound isolated from the soil in the way described is indicated as mannite by its method of preparation, its crystalline form, solubility, and melting point, and this identity is confirmed by the optical properties of the solution and the formation of the compound having the properties of mannite-tribenzacetol when subjected to treatment known to give this compound.

Mannite occurs as a natural product in a large number of plants—in celery, *Apium graveolus*,[2] in *Canella alba*,[3] in *Aconitum napellus*,[4] and in *Syringa vulgaris*[5] It is found in large quantities in several species of fungi; for instance, *Agaricus integer* may contain as much as 20 per cent of its dry weight of mannite.[6]

It is also found as one of the products of certain fermentations of sugar, and by the reduction of dextrose, levulose, or mannose. Its occurrence in soils may be as with many other organic compounds, the result of either a direct addition in plant remains or one of the products of decomposition of other compounds in the soil. The quantity obtained from the soil in which it was found was relatively large, amounting to at least 500 pounds per acre-foot. It has not yet been encountered in any other soil.

RHAMNOSE., $C_6H_{12}O_5.H_2O$.

A glucoside, yielding rhamnose on hydrolysis with mineral acids, was isolated from a soil from New York, the same Volusia silt loam from which choline, already described, was obtained. The method by which the glucoside was obtained was as follows:

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[1] Fischer, Deutsch Chem., 27, 1524 (1894).

[2] Payen, Ann. Chem., 12, 60 (1835)..

[3] Meyer, Reiche. Ann. Chem., 47, 234 (1843).

[4] Smith, Jahr. Fortsch. Chem., 535 (1850).

[5] Ludwig, Jahr. Fortsch. Chem., 508 (1857).

[6] Thorner, Ber. deutsch Chem., 12, 1635 (1879).

The usual sodium hydroxide extract was acidified with acetic acid and filtered. The acid filtrate was neutralized, filtered, and made slightly acid again with acetic acid. To this acid solution lead acetate was added until a precipitate no longer formed and the precipitate removed, washed, and decomposed by hydrogen sulphide. The filtrate from lead sulphide on evaporation to dryness yielded a dark-colored amorphous mass, soluble in water, but yielding no crystals, and having few distinctive properties other than yielding a precipitate with a number of metallic salts. A water solution of this material gave, after short boiling with a mineral acid, a solution that reduced Fehling's solution, indicating that the dark-colored amorphous body was a glucoside or contained a glucoside. On treating a sufficient quantity of this material with boiling dilute sulphuric acid for a short time, filtering from the dark-colored insoluble material formed, neutralizing the filtrate with barium carbonate and evaporating the filtrate to a sirup, crystals were obtained having the properties of rhamnose, a methyl pentose sugar.

These crystals, resembling very much those of cane sugar, were soluble in water and alcohol, were dextro rotatory in water solution, and reduced Fehling's solution and ammoniacal silver nitrate. On distilling with dilute mineral acid, the distillate gave the furfural test with aniline acetate, and on adding phloroglucine and collecting the precipitate it was found to be soluble in alcohol, showing it to be methyl furfural phloroglucide and that the sugar was a methyl pentose.

The crystals of the sugar when purified by several recrystallizations melted at 92–93°, the melting point of rhamnose. By treating the sugar with phenylhydrazine hydrochloride and sodium acetate for several hours on the water bath, bunches of yellow needles were obtained, difficultly soluble in warm water and melting at 180°, properties characteristic of rhamnose phenylhydrazone.[1]

These properties fix the identity of the sugar as rhamnose (iso dulcite), a methyl pentose represented by the formula:

$$CH_3(CHOH)_4CHOH_2O.$$

Rhamnose is not known to occur as such in plants, but it is a splitting product of a number of glucosides of widespread occurrence in vegetation. As such it is part of the glucosides, quercitrin,[2] found in several species of Quercus, xanthorhamnin,[3] in Persian berries; rutin, found in rue and buckwheat;[4] hesperidin,[5] in unripe oranges, and others.

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[1] Fischer, Tafel, Ber. deutsch Chem., **20**, 1091 (1887).

[2] Halaswetz, Pflandler. Ann. Chem., **127**, 362 (1863).

[3] Lieberman, Hormann, Ann. Chem., **196**, 323 (1879).

[4] Forster, Ber. deutsch, Chem., **15**, 215 (1882).

[5] Will, Ber. deutsch, Chem., **20**, 1187 (1887).

It is evident that the presence of a rhamnose yielding glucoside in soil can be easily explained by the probable addition of such a glucoside in vegetable remains. The glucosides that give rhamnose on hydrolysis yield at the same time another body, in most cases, of unknown constitution and often colored. The material formed on heating the soil glucoside with acid was dark colored, little soluble in water, but soluble in alcohol. This body could not be obtained crystalline, and nothing as yet is known regarding its nature or constitution.

The quantity of the rhamnose yielding glucoside obtained from the soil was comparatively large and made up a large proportion of the colored material precipitated by lead acetate from slightly acid solution. Whether this glucoside or similar ones are of common occurrence in soils has not been determined.

ORGANIC SULPHUR COMPOUNDS.

Sulphur is present in organic combination in all plants and animals. It is a constituent part of the protein molecule, no matter of what origin, with the exception of protamines, peptones, and mycoproteid. In plants sulphur is also found in organic form in a number of compounds present in essential oils.

In protein the sulphur is a part of the complex molecule and on hydrolysis it appears as cystein, a thioamine glyceric acid disulphide. Further decomposition may result in the formation of thiolactic acids, mercaptans, ethyl sulphide, or hydrogen sulphide. In essential oils, sulphur may be present in a variety of forms, chiefly organic sulphides or thiocarbamides.

With the knowledge that organic sulphur compounds are added to the soil with every addition of vegetable or animal organic material, it might be expected that some of these compounds would persist in the soil and form a part of the soil organic matter. Many soils give reactions indicative of the presence of organic sulphur; for instance, an alkaline extract to which lead acetate has been added may give, on boiling, a precipitate of lead sulphide, or on boiling the soil with a solution of sodium hydroxide in which a silver coin or piece of silver foil has been placed silver sulphide is formed and coats the coin. Examination of such soils for the presence of cystein, cystine, and thiolactic acids has so far been without any conclusive evidence of the presence of any of these compounds.

But one organic sulphur compound has as yet been isolated from soils. This is trithiobenzaldehyde. Soils containing free sulphur or from which free sulphur may be obtained by steam distillation are rather common. As it seems likely that this free sulphur may be formed from organic sulphur compounds through the activity of microorganisms in the soil, some discussion of it is included under this heading.

SULPHUR.

Free sulphur has been found in a number of soils; in a few cases in a rather large quantity. The method by which free sulphur has been usually obtained is steam distillation. The soil mixed with several volumes of water, placed in a flask or other container, is subjected to a current of steam from a convenient source, the soil container at the same time being kept near the boiling point to prevent undue condensation of steam. The distillate on shaking with chloroform and evaporation of the solvent leaves a residue containing sulphur if any is driven over by the steam. If much sulphur is present it will be apparent, floating on or in the distillate, or may collect in the condenser. All rubber tubing connections and rubber stoppers must of course be avoided in carrying out this process and the freedom of the steam from oil or other impurities be assured.

In one case 0.2 gram of sulphur was obtained from 2,000 grams of soil by this method, in which case the greater part of the sulphur collected in the condenser. In the case of this soil, sulphur could be obtained also by direct extraction with chloroform, but not in so pure a form as by distillation. The soil was, however, exceptional, and the average soil that yields sulphur by this treatment gives but traces sufficient for identification when working with quantities of soil up to 2,000 grams. The source of the sulphur in such cases can be at present but a matter of conjecture.

TRITHIOBENZALDEHYDE, $(C_6H_5CSH)_3$.

Trithiobenzaldehyde was first found in the soil from California, in which succinic acid and lysine, previously described, were found. A sodium hydroxide extract of the soil was acidified with acetic acid and filtered. The acid filtrate was shaken out with several portions of ether, the ether extracts combined and allowed to evaporate at a low temperature on the surface of a little water. There was left an oily residue floating on the surface that in a short time became a mass of rather long interlacing needles, mixed with oily noncrystalline material. This mass was removed from the water by filtration and washed with small portions of cold absolute alcohol. The alcohol removed the greater portion of the oily material and but little of the crystals. These were dissolved again in ether and the process repeated until they were obtained free from color and from adhering impurities.

Thus obtained, this compound was in the form of needles that melted at 225° to 226°, agreeing with the melting point of trithiobenzaldehyde. They were difficultly soluble in alcohol and insoluble or very slightly soluble in water. They were readily soluble in hot acetic acid, separating from this solution on cooling. On heating the crystals with finely divided copper, copper sulphide was formed, and a crystalline sublimate collected on the cool portion of the tube. The copper sulphide gave off hydrogen sulphide readily in treating with dilute hydrochloric acid, and the crystalline deposit melted at 123°, and had the other properties of stilbene or toluylene, $C_6H_5CH.$-$C_{10}C_6H_5$, known to be formed when trithiobenzaldehyde is heated with copper.

The appearance, melting point, and solubility of the compound obtained from the soil indicated its identity as trithiobenzaldehyde, and the reaction and products obtained on heating with copper confirmed this identification. It was fully confirmed by comparison with the pure product obtained by treating an alcoholic solution of benzaldehyde with hydrogen sulphide and adding a solution of iodine in benzol to the product thus obtained. Trithiobenzaldehyde, as a laboratory product, occurs in three forms—a polymerized form, melting at 83° to 85°, obtained by the action of hydrogen sulphide on an alcoholic solution of benzaldehyde, as mentioned above. This, by the action of iodine, is changed to the β form, melting at 225° to 226°, the form obtained from the soil. Another form is obtained together with the β form when a hydrochloric alcohol solution of benzaldehyde is treated with hydrogen sulphide. This, known as the α form, melts at 166° to 167°, and is like the polymerized form, readily changed to the β form by the action of iodine.

Trithiobenzaldehyde is not known to occur as a natural product in plants or animals, and it is difficult to see any connection between it and any of the organic sulphur compounds known to occur in animal or vegetable tissues. Amygdaline, a glucoside occurring in peach kernels, the leaves of the cherry, laurel, and a number of other plants, yields benzaldehyde, as one of the splitting products. It is possible perhaps that through the action of microorganisms in the soil hydrogen sulphide is produced from organic sulphur compounds of plant or animal origin, and this acting on the benzaldehyde forms the trithiobenzaldehyde.

Trithiobenzaldehyde was also found in another soil, the salt marsh soil from Georgia, in which trimethylamine was found. The quantity obtained from the soil from California was relatively large, several hundred pounds per acre-foot; that from the salt-marsh soil was much less.

A determination of the total sulphur in the California soil by fusion with sodium carbonate and a little nitrate gave 0.59 per cent S.[1]

An attempt to determine the sulphur present as trithiobenzaldehyde gave 0.18 per cent S., equivalent to 0.68 per cent trithiobenzaldehyde. The method used in this case was repeated extraction of the soil with boiling glacial acetic acid, evaporation of the extract to dryness, and extraction of the residue with ether. The residue left on evaporation of the ether was then subjected to fusion with sodium carbonate and nitrate and the usual procedure followed, the sulphur found as barium sulphate being calculated to trithiobenzaldehyde.

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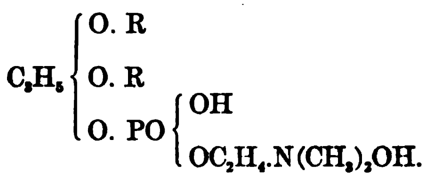
[1] Determination by Mr. W. O. Robinson, of this bureau.

It was found possible by working with portions of soil of 200 grams to obtain crystalline preparations of trithiobenzaldehyde from the California soil by extraction with hot acetic acid, as in the method just described, and purifying the ether extract as in the method first used. The method by which this compound was first isolated, by shaking out with ether from an acid solution, is in all particulars up to the purification of the compound, the same as that used in isolating dihydroxystearic acid. As nearly all soils examined in this laboratory are subjected to this procedure for dihydroxystearic acid, trithiobenzaldehyde would be encountered and recognized if present. In the two soils in which it was found there was no evidence of the presence of dihydroxystearic acid, and while there have been a few cases when there was evidence of traces of trithiobenzaldehyde with dihydroxystearic acid, they have been few. This sulphur compound seems to be of rather infrequent occurrence.

ORGANIC PHOSPHORUS COMPOUNDS.

Phosphorus in organic combination is, like sulphur, constantly present in the tissues and fluids of plants and animals. The forms in which phosphorus occurs in organic combination may be classed under three heads: First, in combination with or as a part of a protein molecule. Nucleo-proteids represent the former and nucleo-albumins or phospho-globulins the latter. Both in breaking down yield phosphoric acid as one of the final products. Second, phosphatides; lecithins are typical of this group. The lecithins are complex compounds analogous to the glycerides and may be represented by the formula:



$$C_3H_5\begin{cases}O.\,R\\O.\,R\\O.\,PO\begin{cases}OH\\OC_2H_4.N(CH_3)_2OH.\end{cases}\end{cases}$$

Where R is a fatty acid radical and the third hydroxyl is replaced by a molecule of the choline ester of glycero-phosphoric acid. The different forms of lecithins are determined by the nature of the fatty acid radical present. They split off glycero-phosphoric acid readily and yield finally under proper conditions free phosphoric acid. Third. Phytin, the calcium magnesium salt of an acid claimed by

Pasternak[1] to be anhydro dimethylene diphosphoric acid, and by Neuberg,[2] Winterstein,[3] and others, to be inosite phosphoric acid. Phytin is of very widespread occurrence in plants, and is the form in which the greater portion of the organic phosphorus is present in vegetation.

It is evident, then, that organic phosphorus compounds are added to soils in every addition of animal or vegetable material, and it is reasonable to expect that some of them would persist for a time at least and make up a portion of the organic matter of the soil. Either with this idea in mind or because of the phosphorus content of fractions of soil organic matter, the question of the presence of organic phosphorus compounds in the soil has had a prominent place in all investigations of this material.

Mulder early observed that the organic matter of soils was not readily freed from phosphorus.[4] From Mulder's time to the present discussion interspersed with some investigation has kept this question rather prominently before agricultural chemists, and very diverse views have been put forward, backed by more or less experimental evidence. Some investigators contend that the phosphoric acid that accompanied the soil organic matter through various operations was simply held by absorption, while others maintained that it was part of an organic molecule.

Schmoeger was probably the first to recognize the possibility of the occurrence in soil of organic phosphorus compounds present in plants and animals[5] and from the increased amount of water soluble phosphoric acid present after heating soil to 150° to 160°, he concluded that nuclein or some related body was present in soils. Later Aso[6] from similar evidence, drew the conclusion that nuclein and lecithins were present in soils.

Later investigations and discussions have ranged around the problem of methods of distinguishing between organic and inorganic phosphorus, or quantitative methods of determining the two forms both in soils and organic material generally. In soil investigations along this line there has been no isolation of any organic phosphorus compound nor any conclusive evidence of the presence of any definite organic phosphorus compound in soils.

The isolation of nucleic acid from soils in this laboratory has already been announced[7] and is at present the only representative of this class isolated and identified. The isolation of choline, a decomposition product of lecithin, has already been described and some evidence has been obtained of the presence of inosite, a decomposition product of phytin, but as yet this compound has not been isolated.

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[1] Compt. Rend., **137**, 439 (1903).

[2] Biochem. Z., **9**, 557 (1908).

[3] Z. physiol. Chem., **58**, 118 (1908).

[4] J. prakt. Chem., **32**, 326 (1844).

[5] Ber. deutsch Chem., **26**, 386 (1893); Biedermann's Centr. Agr. Chem., **26**, 519 (1897).

[6] Biedermann's Centr. Agr. Chem., **34**, 3 (1904).

[7] Shorey, Science, **35**, 390 (1912); Biochem. Bul. I, 104 (1911).

NUCLEIC ACID.

Nucleic acid has been isolated from a number of soils, including the Volusia silt loam and the soil from Cailfornia already mentioned in connection with other compounds.

The method used in this isolation was as follows: The soil was extracted as usual with sodium hydroxide solution. Best results were obtained by using a weaker solution than ordinary, about 1 per cent, and allowing it to act for a short time only. This extract was slightly acidified with hydrochloric acid and filtered. To the acid filtrate a little sodium acetate was added and then three or four volumes of 95 per cent alcohol and the whole allowed to stand some hours. The precipitate was removed by filtration, dissolved again in weak alkali and reprecipitated in the same manner as before. The precipitate, filtered off and washed with 95 per cent alcohol, when dried was an amorphous mass, more or less colored according to the nature of the soil, and contained sometimes rather a large quantity of mineral matter that it was impossible to remove without decomposition of the organic portion. This material had the properties of nucleic acid and on hydrolysis with mineral acid gave the decomposition products characteristic of this group of phosphorus compounds.

On boiling with dilute hydrochloric or dilute sulphuric acid, phosphoric acid was found in solution and could be precipitated under proper conditions with ammonium molybdate and then determined quantitatively by precipitation with magnesia mixture. The same solution contained also pentose sugars, the solutions giving at once the pentose reactions with phloroglucine and orcine, reduced Fehling's solution, were optically active, and gave an osazone with phenylhydrazine, and on continued boiling with dilute acid furfural was given off. The resulting solution in some cases gave tests indicating the presence of levulinic acid, a precipitate of iodoform on adding sodium hydroxide and iodine potassium iodide, and a red color with sodium nitro-prusside and sodium hydroxide. When the original material was heated with stronger acid, 25 per cent sulphuric, for a short time, the solution neutralized and then treated with Fehling's solution as in the method for the separation of purine bases, hypoxanthine and in one case adenine, were obtained in the final filtrate from copper sulphide. On heating the material with 25 per cent sulphuric acid under pressure, 1 to 2 atmospheres, for a short time, the solution neutralized and filtered, cytosine was found in the filtrate. This was separated by precipitation with silver nitrate in solution made slightly alkaline with ammonia.

These reactions and the properties of the material itself and the method of preparation are sufficient to establish its identity as nucleic acid.

Nucleic acids are complex compounds for the most part of unknown constitution. They are found in all nucleated cells of both plants and animals and in such places are a part of a still more complex molecule of nucleo protein.

Nucleo protein when split up by chemical treatment or in the changes that take place in the living organism yields first a protein and a body known as nuclein, and the latter breaks up still further into another protein and nucleic acid. The nucleic acids, of which there are apparently a number differing in composition and constitution according to their source, are distinguished by certain general properties and the products they yield on hydrolysis. As ordinarily obtained they are amorphous compounds, soluble in alkalies and rather resistant to change in alkaline solution. They are precipitated from alkaline solution by mineral acids in the presence of a large volume of alcohol. Some of them are precipitated by this treatment only when sodium acetate is present also.

On hydrolysis they always yield phosphoric acid, a pentose sugar, purine bases, and pyrimidine derivatives. The nucleic acids prepared from soils, while differing considerably in composition according to the nature of the soil, were constant in yielding phosphoric acid, pentoses, one or more purine bases, and a pyrimidine derivative. Among the purine bases xanthine and guanine have not yet been detected in the hydrolysis products and but one pyrimidine derivative cytosin has been obtained. The widespread distribution of nucleic acids in plants and animals and their resistance to decomposition under certain conditions indicates that their occurrence in soils is due either to their persistence after addition to the soil in plant or animal remains, or to their building up by microorganisms in the soil from other less complex material.

So far as observed nucleic acids seem to be constant constituents of the organic matter of soils, and in the absence of a method of determining them quantitatively in such a complex body as the soil it can only be stated that the evidence is that in many cases they form a very appreciable portion of the organic matter of soils.

GENERAL METHODS.

In the foregoing pages methods have been described by which 14 organic compounds have been isolated from soils. These, added to the number reported in previous bulletins, make the total number of definite organic compounds isolated from soil 35. Among those described in this bulletin are members of four classes of organic compounds not represented in previous reports, viz, aldehydes, glucosides, organic sulphur, and organic phosphorus compounds. Some of the compounds have been found as the result of a direct search for them—for instance, choline and lysine; others have been found accidentally in the carrying out of methods for compounds before isolated—for instance, trithiobenzaldehyde; and still others have resulted from modifications of methods made often for no other reason than that such modifications often bring unexpected results. This results in considerable complexity of methods, and as the work progresses the complexity promises to increase and makes desirable some general discussion of the methods that have been used.

ALKALINE EXTRACTION.

Investigation has shown the presence in soils of a number of organic compounds that are quite soluble in water. These can not be isolated from or detected in a water extract, but have been isolated from an extract made by treating the soil with a dilute solution of sodium hydroxide. This may be explained in several ways: First. The compounds are generated from some insoluble and probably more complex compounds by the action of the sodium hydroxide. This is the explanation that probably occurs first to those not familiar with the properties and antecedents of the compounds or with the general nature of the organic matter of soils. Second. The compounds may be present in the soil in insoluble form in combination with some of its mineral constituents, and these are soluble in alkaline solution and broken up by subsequent treatment with acid. This is probably the case with some of the organic acids isolated. Alumina in considerable quantity is always present in the sodium hydroxide extract, and every indication points to the presence in the soil of combinations between some of the organic acids and alumina and other inorganic bases. In such a case if the acid were one possible of being extracted from water solution with ether it would be found in the ether which had been shaken with the filtrate after acidifying the alkaline extract and filtering. Third. The compounds that under ordinary circumstances would be soluble in water are held in the soil in more or less insoluble form by being incorporated in granules or aggregates of insoluble material, such as resins or waxes. Resins and bodies of a similar nature make up a very large proportion of the soil organic matter soluble in alkalies. On treatment with sodium-hydroxide solution these resinous bodies go into solution, and the other organic compounds are set free, so to speak; that is, they are found in the filtrate when the resins are precipitated in a finely divided condition by acidifying. Whether there is a chemical combination between the alkali and the resins, a formation of sodium salts of resin acids, whether it is true solution or so-called colloidal solution, are questions, important of course, but questions whose settlement does not effect the general statement just made. Fourth. The soluble organic compounds may be held absorbed by the insoluble finely divided organic matter. That this material has a great absorptive power is well known, and the fact that some organic compounds soluble in water can be obtained from the soil by continued leaching with water indicates that they are held there in this way.

Careful consideration of all the facts connected with the isolation of the organic compounds so far described must result in the elimination of the explanation first mentioned. There is no evidence that any of the compounds so far found in soils can be formed from other material by simple treatment with cold 2 per cent sodium hydroxide for a few hours. The general statement, however, that no change is or can be brought about by this treatment can not be entertained, for it is known that the character of protein is changed even by short contact with alkaline solution and that acids in small quantity are generated from sugars in the same way. This makes it necessary to decide in each individual case whether the particular compound isolated could have been generated from some other compound or compounds by any of the treatments involved in the methods used. For instance, the purine bases, xanthine, and hypoxanthine, are found as such in plants and animal tissues and in addition are formed by the hydrolysis of nucleic acids with strong mineral acids and heat. They are not known to be derived from any other source than nucleic acids and from these only by strong chemical reagents. The nucleic acids from which they are formed are quite resistant to the action of alkalies and there can be but one conclusion that when they are isolated from soil solution they exist as such in the soil. A similar line of argument applies to the hexone bases and the pyrimidine derivatives. In the case of organic acids the isolation of a free acid does not necessarily imply that this acid occurs free in the soil. It may, and probably in most cases does, occur there as a salt and is set free by the treatment to which the soil has been subjected. Without going into each case at this time it may be confidently stated that investigation will show that there is no evidence pointing to the generation of any of the organic compounds isolated from soils from other compounds of different constitution, and that such compounds occur as such in the soil, and in the case of acids either free or combined with bases.

UNIFICATION OF METHODS.

With the growing complexity of methods incident to the isolation of additional organic compounds from the soil the desirability of possible simplification or unification of these methods suggests itself. At present the experience of these working along this line supports the view that, once an organic compound has been found in soils and a reliable method devised for finding it, the surest way to determine its presence or absence in other soils is to use a sample of the soil for a special search for that compound alone. There are two reasons for this: First. The methods used begin to diverge once an alkaline extract is obtained. An alkaline, neutral, or acid solution may be required, or if acid, it may be necessary to decide whether acetic, sulphuric, nitric, or some other acid should be used. For instance, starting with a sample as large as 50 pounds of soil, if an attempt be made to include a search for all compounds the extract will be divided and subdivided so often that the units will represent in many cases too small a portion of soil for the isolation of any compound. On the other hand, if the sample be made large enough to overcome this difficulty the volume of extract and the whole procedure would be beyond the limits of any laboratory equipment. Second. Different soils require different treatment, and knowledge of the peculiarities of any soil can only be obtained by working with it. It is seldom that an organic compound can not be separated from mixtures in more than one way, but it frequently happens that one way will be successful with one soil, while with another soil some modification must be introduced. The difference in methods that have to be resorted to in order to overcome difficulties presented may involve the kind of acid used, the concentration of the extract, the nature of the precipitant, the removal of one compound before another is sought, or the manipulation of the small crystalline residues obtained in the final stages.

While the best results in the isolation of organic compounds from soil will be obtained by working separate portions, probably not exceeding 50 pounds each, there are many points where compounds can be grouped together or where the extract from which one compound has been separated can be used for the isolation of others. For instance, the purine bases form a group, the hexone bases another, and the acid extract from which dihydroxystearic acid or trithiobenzaldehyde has been separated by ether can be used for other separations.

In carrying out the procedure in the methods described in the foregoing pages a number of unexpected difficulties have been encountered and some of these have occurred so often and in so many different places that some mention of them is warranted.

PRECIPITATION WITH METALLIC SALTS.

When a neutral soil extract obtained in the usual way by extracting with sodium hydroxide, neutralizing, and filtering, is treated with a metallic precipitant such as lead acetate, silver nitrate, mercuric nitrate, etc., the precipitate is usually voluminous and may contain a great variety of compounds. For instance, the precipitate with silver nitrate might contain, of the compounds already isolated from soils, picoline carboxylic acid, dihydroxystearic acid, oxalic acid, saccharic acid, nucleic acid, and if slightly alkaline, purine bases, pyrimidine derivatives, and histidine, besides unidentified organic matter and some mineral matter. It is seldom that a soil extract will give a precipitate of any single compound with any of these metallic salts. This difficulty may be met in a variety of ways, such as fractional precipitation, separation of the residue obtained into fractions by treatment with solvents, ether, absolute alcohol, etc., or reprecipitation, either with the same precipitant or others.

PRECIPITATION WITH PHOSPHOTUNGSTIC ACID.

The precipitates formed by phosphotungstic acid in sulphuric acid solution, while usually not so voluminous as those produced by the metallic precipitants in neutral solution, like them, usually contain a medley of compounds. It can for this reason be used either for freeing a solution from material not wanted or as a preliminary precipitant followed by fractionation of the material by reprecipitation with other metallic salts. In decomposing the phosphotungstic acid precipitate the use of a mixture of 4 volumes of acetone and 3 of water, as suggested by Wechsler,[1] as a solvent for the precipitate before treatment with barium hydroxide was found an improvement over the procedure usually followed.

In the use of phosphotungstic acid as a precipitant it was sometimes found in carrying out the method ordinarily used that after the excess of barium had been removed by carbon dioxide there was still barium in solution, owing, probably, to the presence of some organic acid stronger than carbon dioxide. This barium could be removed by careful treatment with sulphuric acid and filtration from barium sulphate. The filtrate contained an unknown acid. If this acid should occur together with a base precipitated by phosphotungstic acid such as lysine, the identity of the final products might be difficult to determine.

CALCIUM SULPHATE CONTAMINATION.

Nearly all soils contain calcium and sulphates, so that under certain conditions gypsum crystals are deposited from the soil extracts. Under certain conditions calcium sulphate is precipitated or carried down, perhaps as a double salt, with metallic precipitants and on decomposing with hydrogen sulphide is found in the filtrate and crystallizes out in the residue. It is usually present when lead, silver, copper, or mercury precipitates are formed in slightly alkaline media. As the calcium sulphate crystals are often similar in appearance to the organic compounds sought, they may mislead and when, as often happens, their solubility is nearly the same as the organic compounds accompanying them, separation is troublesome. Recognition of the presence of calcium sulphate in such residues and repeated evaporations and extractions with absolute alcohol will often overcome this difficulty.

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[1] Z. physiol. Chem., 73, 138 (1911).

CALCAREOUS SOILS.

Calcareous soils yield often but a small portion of their organic matter when treated with sodium hydroxide solution unless previously leached free of lime with hydrochloric acid as in the ordinary humus determination. In some cases this is an advantage, since the large quantity of amorphous resins that make up so large a part of the humus often interferes with the separation of other organic compounds. The first isolation of histidine and arginine was from a dark-colored calcareous soil that on treatment with alkali yielded a light straw-colored extract from which these compounds were obtained. After removal of the lime with dilute acid this soil gave a very dark-colored alkaline extract. It has been thought that perhaps for the isolation of some compounds the addition of lime to noncalcerous soils before extraction with alkali would be advantageous, but this has not been thoroughly tested.

CHANGES IN ORGANIC COMPOUNDS.

It is quite evident that under ordinary field conditions there is going on a constant change and rearrangement of the organic compounds in the soil. Compounds added to the soil in vegetable or animal débris are being broken down into simpler compounds by the activity of enzymes and microorganisms, and the simpler compounds used as food by other forms of the microflora may be built up into other more complex compounds. It follows then that although certain compounds may be nearly always present, the quantitive relations are constantly changing. This change is not confined to soils in the field. Samples taken for examination and stored in the laboratory are also subject to change in the character of the organic compounds present. This has been found to be particularly true with regard to certain compounds. A soil from which dihydroxystearic acid had been isolated several times from separate portions after remaining in storage several months became so changed that but traces of this compound could be found. Observations covering a shorter time indicate that salicylic aldehyde and mannite tend also to disappear when the soils are stored. It follows then that if duplication of results be made a criterion in deciding the presence or absence of any organic compound in a soil, the duplicates should coincide in time of examination as well as method of treatment and source of sample.

CONCLUSION.

The organic compounds isolated from soils and described in this bulletin, together with those previously reported, make a list that may be classified as follows: Thirteen organic acids, nine organic basic compounds, three carbohydrates, two aldehydes, two alcohols, one each hydrocarbon, glyceride, ester, sulphur compound, phosphorus compound, and an acid hydride. This list viewed in the light of possible compounds is so far from complete as to be properly regarded but a beginning, still, when classified, it probably indicates roughly the proportions of the classes of organic compounds present in soils. Organic acids make up a large proportion of the organic matter in the soil and when the great variety of acids in plant tissues and the proportion of the organic matter of plants made up of this group of compounds is considered, as well as the fact that the other groups of compounds in both plants and animals yield acids on decomposition, this preponderance of organic acids in soils becomes a matter not only easily explained but one to be expected. There is no reason why any of the organic acids found in plants or found in the decomposition of plant or animal remains should not be found at some time in some soils. The great variety of organic acids possible from these sources, and their susceptibility to change under soil conditions tend to bring about an individuality of soils in respect to organic acid content much more pronounced than is possible with any other group of organic compounds. As has already been stated there is every indication that in most cases the organic acid isolated from soils is present in the soils as salts. In the case of acid soils no conclusive evidence has been obtained of the nature of the acid to which the acidity is due. It is worthy of note that dihydroxystearic acid, one that has been shown to be of rather common occurrence, has not been found in soils that were decidedly acid in reaction.

Organic bases that occur in plants or animals or arise in the decay of the same are comparatively few in number, and the nine so far isolated from soils probably make up half or more of those of likely or probable occurrence in soils. Organic bases as well as acids no doubt often are present in the soil in combination either with organic or mineral acids. The demonstration of the presence of organic bases in soils is of rather more than usual interest in view of the prevailing idea that soil organic matter is primarily acid, and further from the fact that these nitrogenous compounds have been shown to be directly assimilated by plants as well as to furnish much of the material from which nitric acid is generated in the process of nitrification.

The carbohydrates are represented by pentosans, apparently a constant constituent of soils, a glucoside containing rhamnose and mannite. These form but a very small part of the carbohydrate material that is added to soils and probably but a small part of that which persists in the soil. The susceptibility of the carbohydrates, starches, and sugars, to decomposition by enzymes and microorganisms makes it likely, as has already been pointed out, that these plant constituents either disappear altogether or are represented by some of the products of decomposition, largely organic acids. Oxalic and saccharic acid probably have their origin in this way and there are no doubt many other acids not yet found that are derived in like manner.

Aldehyde compounds seem to be rather constant constituents of the soil organic matter. The salicylic aldehyde isolated from one soil is the only identified representative of this class. The unidentified aldehyde isolated or a similar body or mixture is found in nearly all soils.

Hydrocarbons represented by hentriacontane, one representative each of glycerides and resin esters, and alcohols represented by agrosterol and phytosterol, are usually found in the humus precipitate formed on acidifying the alkaline extract of the soil. The present investigations do not include any examination of this material additional to that presented in previous bulletins.

The fact that there are many soils that give tests indicating the presence of organic sulphur compounds in which trithiobenzaldehyde can not be found indicates that there are other organic sulphur compounds in soils. The very definite way in which sulphur-containing proteins yield cystin on hydrolysis, the easy change of this to cystein on reduction and the further ready change of both these to thiolactic acids make it probable that some or perhaps all of these will ultimately be found in soils.

Phosphorus organic compounds are represented by nucleic acid, of which there are probably several. The only nucleic acids of plant origin that have been investigated to any extent are those from yeast and from the wheat embryo. These are said to be identical and it may be that the nucleic acids of plant origin do not present so great a variation in structure as do those of animal origin. It has been found that some nucleic acids under certain conditions split into compounds less complex than the original but more complex than the compounds usually considered as the end products, pentoses, bases, and phosphoric acid. Under certain conditions the split may result in free phosphoric acid and compounds known as nucleosides. The nucleosides are combinations of the pentose and purine base. Under other conditions the split may result in a compound known as a carbohydrate phosphoric acid. One of these compounds, *d* ribose phosphoric acid, $C_5H_{11}O_8$,[1] results from the decomposition of inosinic acid, while another, thymo-hexose-phosphoric acid, $C_{11}H_{17}U_2PO_{10}$,[2] results from the decomposition of thymus nucleic acid. There has been obtained some evidence of the presence of compounds of a similar nature in soils, but as yet no separation in a form definite enough for identification. There is also considerable evidence pointing to the presence in soils of both lecithin and phytin, the two other representatives of phosphorus organic compounds.

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[1] Levene & Jacobs, Ber. deutsch Chem., 41, 2703 (1908).

[2] Levene & Mandel, Ber. deutsch Chem., 41, 1905 (1908).

The general relationships between the different groups of organic compounds found in soils has been casually referred to under individual compounds, but can be more profitably presented in one statement.

The organic acids, of which there are a great number in plants and probably a larger number in soils, may, when found in soils, be the result of direct addition of such acids in vegetable débris or of the decomposition and rearrangement of other organic matter that takes place in soils through the activity of microorganisms. The acids that originate through decomposition may be derived from almost all other classes of compounds. The breaking down of fats, glycerides, or protein, or the oxidation of carbohydrates, alcohols, aldehydes, or hydrocarbons, may furnish organic acids and these acids may be changed from one member to another of the same series or other series by the process of oxidation and reduction that accompany the biological activity of soils.

Many of the organic bases are rather intimately connected with protein, either those like histidine, arginine and lysine that result from the breaking down of the protein molecule or the purine bases, xanthine and hypoxanthine and adenine, or the pyrimidine derivative cytosin that results from the splitting of nucleic acid, itself a splitting product of the more complex nucleo-protein. The simpler bases, choline and trimethylamine, as has been mentioned, are decomposition products of lecithin. Lecithins are present in practically all growing cells both of plants and animals, and choline often occurs as such. Trimethylamine, while occurring as such in plants is much more apt to be found in decomposing organic material where no doubt it is derived from choline or the antecedent lecithin.

Carbohydrates are rather poorly represented among the compounds isolated from soil organic matter when the abundance of such material in vegetable remains is considered, but it seems probable that there are a number of the compounds of the group still undetected. The pentose sugars that are always formed on heating soils with mineral acids, may be formed from pentosans, from nucleic acids or from glucosides, and there is no method of determining their origin in any case except isolation of the parent body as was done with nucleic acid, pentosan, and the glucoside, which yielded rhamnose.

With regard to the character of organic sulphur compounds in the soil the investigation at the present time leaves much to be desired. The one compound isolated is apparently not a normal constituent of soils, and as has already been noted, it is difficult to see any relation between it and the sulphur compounds known to occur in plants or to result from their decomposition.

The isolation of nucleic acid from soils, while by no means the last word on the question of the organic phosphorus in soils, at least settles the question whether there are organic phosphorus compounds in soils. The isolation and identification of nucleic acid from a number of soils leaves no longer any doubt in this regard. The common occurrence of the purine base, hypoxanthine, the occasional occurrence of xanthine and adenine and of cytosine is, of course, intimately related to the presence of nucleic acid, as is also a portion of the pentose sugar obtained on hydrolysis.

Much of the discussion found in agricultural literature regarding organic phosphorus compounds in soils has centered around methods for distinguishing between organic and inorganic phosphorus. Some of the discussion has been futile from lack of recognition of the presence of nucleic acids and due consideration of their properties. They are often very easily decomposed by the action of mineral acids, even when dilute and at ordinary temperatures. When a soil is extracted with dilute alkali, the alkaline extract contains nucleic acid as well as probably some inorganic phosphorus compounds. When the solution is acidified with a mineral acid and the precipitate washed with dilute acid usually very little phorphorus is left in the so-called humus precipitate. For instance, a soil containing 0.316 per cent phosphorus gave an extract with 2 per cent sodium hydroxide, which contained 0.185 per cent phosphorus, calculated on the soil. On acidifying this extract and washing the precipitate, this contained only 0.0006 per cent phosphorus. The acid filtrate from this precipitate then contains all but a trace of the phosphorus originally extracted by the sodium hydroxide. This may be the original nucleic acid and the inorganic phosphorus in the original extract, but if the procedure has been of some duration the nucleic acid is decomposed, free phosphoric acid resulting. If care is taken to perform this operation in a short time, nucleic acid can be recovered from the acid filtrate by adding sodium acetate and several volumes of alcohol, but the quantity obtained will be decreased by several hours' standing, as well as by an excess of acid, and may disappear altogether in a few days. Individual soils differ markedly in this respect. The differentiation between the phosphoric acid combined in nucleic acid and free phosphoric acid is experimentally so difficult that any attempt to determine quantitative relationships between them is at present futile. When, by the procedure just outlined, nucleic acid is obtained by exercising all care to prevent decomposition, and when by standing some hours less is obtained, there is still no means of ascertaining whether the quantity of nucleic acid obtained in the first instance represented all that was extracted from the soil. In other words, there is no standard to judge by and with all precautions some free phosphoric acid may be generated from the nucleic acid.

In this connection it may be well to mention another point that has to do with both organic phosphorus and sulphur compounds. This is the quite different characters of the two classes of compounds. Nucleic acids and lecithins may be regarded as substituted phosphoric acids, the phosphorus being, so to speak, in the phosphoric acid form, and phosphoric acid as such being split off on the least provocation. The same is probably true of phytin, although its constitution is not so well established. In organic sulphur compounds on the other hand, the sulphur may usually be regarded as in the place of oxygen, for instance, in trithiobenzaldehyde there is the group CSH in the place of COH. When such compounds split, free sulphur or a sulphide usually results, few, if any, having sulphur in such form as to split off sulphuric acid, viz, sulphur in combination with oxygen. There is then no analogy between the relation of organic phosphorus compounds and phosphoric acid on the one hand and organic sulphur compounds and sulphuric acid on the other.

As was stated in the introduction there was in carrying out this work no attempt made to include all the organic matter in any one soil in the investigation. The aim was rather to isolate compounds not heretofore found in soils with the hope, not only of adding to the knowledge of the organic matter of soils in general, but also of throwing light on such abnormal characteristics as some particular soil presented. For this reason it is not possible to make any specific or even general statement as to what properties of the soil organic matter the 15 compounds described in this bulletin represent.

There seems to be an idea prevalent in some quarters that the organic chemical compounds shown to be present in the soil organic matter are rather incidental contaminations of the larger, more important, and "still mysterious" humus. Now while it is true that there still remains a large proportion of the organic matter unidentified, it is not so large in the soil of average organic content as many imagine. This unidentified portion is now, known to be made up largely of compounds related to the resins, and the identification of its constituents is difficult because the chemistry of this class of plant constituents is still in a chaotic condition, and there is almost nothing definite with which to compare an isolated soil resin or resin acid.

The compounds described are all extracted from soil by dilute alkali and are a part of the organic matter included in the general term humus, but they are for the most part not precipitated when this extract is acidified. In other words, they are a part of the humus extract, but not included in the "matiere noir" except as held in it by absorption. Except in the case of soils high in humus content, this portion of the organic matter of soils is one-half or more of that extracted by alkalies and with the knowledge of the compounds present in this fraction and the methods available for their isolation or determination it is in many cases possible to account for nearly the whole of it. The work here reported bears out a conclusion reached in summing up previous work that while it emphasizes the complex character of the organic matter of soils, it demonstrates at the same time that this complexity is not so great that the chemical nature of all of the organic soil material can not be determined by modern methods of research.

SUMMARY.

In this bulletin there is presented the result of further research into the chemical nature of the organic matter of soils. The isolation of 15 organic compounds from this material is described, 14 of which have been identified. These together with those isolated before and described in previous bulletins make 35 organic compounds isolated from soils.

The methods by which these compounds were isolated are described, the manner in which they have been identified pointed out, and the possible sources of the compounds discussed. The substances here described belong to 6 classes of organic compounds, 3 classes, aldehydes, organic sulphur, and organic phosphorus compounds being classes not represented among those isolated and described before.

The compounds isolated have been classified as follows: Thirteen organic acids, 9 organic bases, 3 sugars, 2 aldehydes, 2 alcohols, and 1 each, hydrocarbon, glyceride, resin ester, sulphur compound, phosphorus compound, and an acid anhydride.

The relationship between these groups as well as that between the isolated compounds and the organic matter in general is discussed.

The compounds isolated and described here are oxalic acid, $C_2H_2O_4$; succinic acid, $C_4H_6O_4$; saccharaic acid, $C_6H_8O_{10}$; acrylic acid, $C_3H_4O_2$; lysine, $C_6H_{14}O_2N_2$; adenine, $C_5H_5N_5$; choline, $C_5H_{15}O_2N$; trimethylamine, C_3H_9N; salicylic aldehyde, $C_6H_4OH_1COH$; mannite, $C_6H_{14}O_6$; rhamnose, $C_6H_{14}O_{10}$; trithiobenzaldehyde, $(C_6H_5CSH)_3$; nucleic acid, of unknown constitution, and an unidentified aldehyde.

The conclusion is reached that the work, like that previously reported, while it emphasizes the complex character of the organic matter of soils, bears out the contention that this complexity is not so great but that the chemical nature of all of the organic matter of soils can be determined by modern methods of research.

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 89.
MILTON WHITNEY, Chief.

THE CHEMISTRY OF STEAM-HEATED SOILS.

BY

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Scientist in Charge of Fertility Investigations,
AND
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Scientist in Fertility Investigations.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., June 7, 1912.

SIR: I have the honor to transmit herewith the manuscript of a scientific paper entitled "The Chemistry of Steam-Heated Soils," by Dr. Oswald Schreiner, in charge of Soil Fertility Investigations, and Mr. Elbert C. Lathrop, scientist in Soil Fertility Investigations, of this bureau.

The results set forth therein are of fundamental importance in connection with biochemical processes in soils, and I therefore recommend its publication as Bulletin No. 89 of the Bureau of Soils.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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THE CHEMISTRY OF STEAM-HEATED SOILS.

INTRODUCTION.

The subject of the effect which heat has upon soils is rather prominently before agricultural investigators at the present time. This subject has received increasing attention during the last decade, particularly from the point of view of sterilization and partial sterilization. There has been much valuable information obtained along the biological lines concerned; also much speculation in this regard without due consideration of the chemical and physical changes involved, owing largely to the fact that these were not known or but imperfectly understood. The biological factors can not and should not be ignored, but it must be remembered that they are only of significance or interest in the light of the biochemical changes which they produce in the soil. Moreover, any biochemical changes produced in the soil through other means, be they cultural or by the addition of manures and fertilizers or by the influence of steam heating, in turn affect the biological activities. The chemistry, therefore, of the soil both before and after heating in sterilization work becomes of the greatest significance to the biological worker.

Since heat activates the changes going on normally in soils, it is obvious that a study of heated soils also throws light upon the biochemical changes taking place in soils under field conditions. The present bulletin is a contribution to the knowledge concerning soil organic matter and the changes which it undergoes. It is hoped that the results set forth will be of interest and value alike to the soil biologist and the practical worker with sterilized soils in greenhouse or field, as well as to the soil investigator dealing with the subject of the soil's fertility and infertility.

THE EFFECT OF HEATING ON SOILS.

Until the investigations of Franke[1] in 1888 soil investigators did not consider that the process of sterilization of soils by heat effected any changes in either the mechanical nature or chemical composition of the soils so treated. In attempting to explain the increased yield observed on sterilized soils he decided that the steam heating of the soil had caused some chemical changes. He found that the heated soils contained a great deal more soluble matter than the unheated soils; the moor soils contained more than twice as much and the sandy soils not quite twice as much. The increased productiveness was, therefore, to be explained by the fact that by the process of sterilization more material was rendered soluble and made available for plant use. Schmoeger[1] found that from a soil which had been heated in an autoclave at 140° to 160° C. for several hours he could extract with 12 per cent hydrochloric acid almost as much phosphate as was obtained from the ash of the soil, and much more than could be obtained in the same way from the soil unheated. He concluded that a part of the phosphoric acid existed in the soil in the form of lecithins or nucleic acids. Liebscher[2] at the same time found that by steaming the soil there was an increase in soluble phosphate and also an increase in soluble nitrogenous compounds, which thus became available to plants. According to him, steam sterilizing may be viewed as nitrogen fertilizing.

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[1] Ber. bot. Ges., 6, lxxxvii (1888).

Deherain and Demoussy[3] found that the production of carbon dioxide obtained by heating soils increased in a measure proportional to the temperature until 110° is reached. The quantity obtained they considered higher than could be attributed to bacterial action. At a temperature of 120° decomposition is produced by oxidation and reduction, it being found that some soils at this temperature absorbed more oxygen than was given off as carbon dioxide. By sterilizing the soil they observed an increased ammonia-nitrogen content and were able to prevent nitrification, although the sterilized soil when inoculated with a portion of the unsterilized soil produced larger quantities of nitric nitrogen than did the unsterilized soil.

Pfeiffer and Franke[4] confirmed Liebscher's view that there is an increase in assimilable nitrogen in the heated soil, and showed large increases both in crop yield and in nitrogen assimilated from the heated soil as compared with the unheated soil. Richter[5] heated a garden soil and found that the heating had increased the absorptive power of the soil for water and the amount of easily assimilable nitrogenous compounds; the total water-soluble organic matter had been increased almost threefold.

The first account of the bad effects of soil sterilization on plant growth is given by Dietrich,[6] who states that, although there is an increase in soluble nutrients, especially nitrogenous compounds, in the heated soils, there is also a poison formed by the alteration of the organic matter of the soil Thus the plants are influenced by two factors in the heated soil which are opposed to each other, one the more available plant nutrients, and the other the poisons arising during and following the sterilization. According to the amount of this poison and the sensitiveness of the plant to it, the one or the other factor predominates, and where the plants were less susceptible to the poison there was observed an increased absorption of soluble nitrogen by the plants. The addition of calcium carbonate to the soil to be sterilized prevented or almost prevented the poisonous action. Schulze[1] also noticed the harmful effect, and he says in this regard that not only in the physiological properties, the killing of bacteria, but also in the physical chemical properties of the soils changes are produced by sterilization. The difficultly soluble material of soil, mostly of humus nature, is thus made more soluble, and this soluble material has a harmful effect on the growing plants, but this effect varies with different soils. He further states that dry weight of the plants grown on the sterilized soil was as low as 26 per cent of the dry weight of those grown on the unsterilized soil. The effect of this injurious substance does not last through the whole life of the plant, for as the plants grow older they become more vigorous on the sterilized soils. Koch and Luken[2] found that with soils which had received applications of fertilizers in each case the heating produced immediate injurious effects, though these were found to be unimportant if the plants were started in the summer instead of in the spring.

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[1] Ber. deutsch. chem. Ges., **26**, 386 (1893).

[2] Deutsch. Landw. Presse, **20**, 976 (1893).

[3] Ann. agron., **22**, 305, (1896).

[4] Landw. Vers.-Stat., **46**, 117 (1896).

[5] Landw. Vers.-Stat., **47**, 269 (1896).

[6] Jahresb. Landw. Vers., Marburg, 1901-2; Bied. Centrlb., **32**, 68 (1903).

Darbishire and Russell[3] in 1907 made a study of the effects of partial sterilization on soils, using for the purpose of sterilization volatile antiseptics and steaming at 95° and 120° C. They found that the crops could get from the heated soils three times as much nitrogen and twice as much phosphoric acid and potash as from the unheated soils and that the increase in dry matter in the plants was very considerable. Analysis showed an increase in the amount of nitrogen, phosphoric acid, and potash taken up by the crop and in the percentage of nitrogen and phosphoric acid in the dry matter. They believed that the increased availability of the plant nutrients is connected with the modification of the bacterial flora, brought about by partial sterilization, although when the soils are sterilized by heat a certain amount of decomposition also takes place.

Two years later Russell and Hutchinson[4] report further experiments along this line. They believe that the effect of partial sterilization on soils is to destroy the larger phagocytic microorganisms which inhibit the growth of the beneficial bacteria. They state that the increased productiveness of partially sterilized soils is due to an increase in the quantity of ammonia present, and that this increase is the result of an increased decomposition of soil substances by bacteria. When the soil was heated to 95°, there was a small immediate production of ammonia and little change took place for a few days; this period of inaction was followed by one of rapid change, during which ammonia was produced in considerable quantities; lastly, a slow period of change set in and the further production of ammonia was small. Soil heated to 125°, at which temperature all bacteria are killed, behaved very differently; after the first production of ammonia by heating there was no further change. Heating the soil rendered it unfit for the development of the nitrifying bacteria; apparently during the heating a compound was formed which was toxic to them and not to the ones producing ammonia. However, by the time the second crop was growing on the heated soil the nitrifying bacteria added developed abundantly, suggesting that the toxic body slowly disappears from the soil. In their relation to plant growth the heated soils were peculiar in that they supplied not nitrates but other nitrogenous compounds to the plants. The greater activity of nitrifying than of ammonifying bacteria in normal soils they attribute to the presence of the larger organisms, particularly protozoa, which through their destruction of the ammonifying bacteria constitute a limiting factor in soil fertility.

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[1] Jahresb. Vertreter angew. Bot., 1, 37 (1903); Centrlb. Bakt. Par., 2, abt. II, 716 (1903).

[2] Jour. f. Landw., 55, 161 (1907).

[3] Jour. Agr. Sci., 2, 305 (1907).

[4] Jour. Agr. Sci., 3, 111 (1909).

At about the same time Pickering[1] conducted experiments in regard to germination and plant growth on sterilized soils, which may be summarized as follows: Soils which have been heated to temperatures from 60° to 150° C. behave unfavorably to the germination of seeds, the total number of seeds germinating decreasing in most cases, and the time necessary for their germination increasing with the temperature of heating. According to Pickering, the retarding effect on germination can not be explained by an alteration in the bacterial condition of the soil, for the alteration extends progressively at temperatures beyond that sufficient to kill all bacteria, and, moreover, no similar results were obtained with sand, even when it had been thoroughly impregnated with soil bacteria to begin with. By heating the soil an increase of soluble constituents occurs. There is an increase in mineral matter, but especially in organic and nitrogenous matter; the increase in the latter has been found to be proportional to the temperature of heating and to the increase in the time required for germination. The increase in the time of germination appears to be due, he concludes, to the formation of a nitrogenous compound in the soil which is inhibitory to germination. This compound was sufficiently stable in solution for an extract of a heated soil to affect a normal soil when added to the latter; it also does not seem to be destroyed when the soil containing it is kept at a low temperature for several months, but at higher temperatures and in the presence of moisture it generally loses its inhibitory properties, probably through oxidation. This substance is not an acid, for the soils were heated in the presence of an excess of chalk and no acids were formed. The production of the substance inhibitory to germination seems to be a property common to many soils. The substance which is toxic to germination is not necessarily so to plant growth, or it may be destroyed before growth becomes active. The heated soils behaved toward the starting of the growth of young apple trees as it did toward the germination of seeds, the starting of the growth being considerably delayed; later, however, the growth of the trees became very vigorous.

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[1] Jour. Agr. Sci., 2, 411 (1908); Ibid., 3, 32 (1908).

Seaver [1] and Seaver and Clark [2] studied the effect of heated soil on certain fungi, *Pyronema omphalodes*, which apparently developed only on heated or burnt soils.

From a study of the effects of steam sterilization on the water-soluble matter in soils, Lyon and Bizzel [3] conclude that by the steaming of soils substances injurious to plant growth arise. The growth of wheat plants on steamed soil served to hasten its recovery from the injurious effects of heating, and the time required for the various soils to recover from these effects was, with one exception, in the order of their relative productiveness. The steaming greatly increased the soluble nitrogenous compounds and phosphoric acid; the nitrates were reduced to nitrites and to ammonia, but most of the ammonia was formed from organic matter. On standing, without plants growing upon them, the steamed soils gradually decreased in their content of soluble matter, including ammonia and nitrogenous organic matter. If, however, the steamed soils were planted, they showed much more soluble matter at the end of three months than did the unplanted, steamed soils.

In greenhouse work, particularly for the forcing of plants, steam sterilization of the soil is largely used. Stuart,[4] Stone and Monahan,[5] and Stone and Smith [6] report experiments along this line. They find that in the forcing of plants, particularly lettuce and cucumbers, soil sterilization is necessary. The sterilization has the effect of killing the nematodes and lessening the amount of infection, especially *Rhizoctonia* in lettuce. It also increases the growth of the plant, as high as 33 per cent increased yield having been obtained by such procedure. For the purpose of sterilizing large beds of soil, various forms of apparatus have been designed and are reported by Rudd,[1] May,[2] Selby,[3] and the experimenters mentioned above.

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[1] Mycologia, 1, 131 (1909).

[2] Ibid., 2, 109 (1910).

[3] Cornell Agr. Expt. Sta. Bul. 275 (1910).

[4] Vermont Expt. Sta., Ann. Report, 1905, p. 297.

[5] Mass. Expt. Sta., Report, 1904.

[6] Mass. Expt. Sta., Report, 1902, p. 38; Ibid., 1901, p. 57.

It is, however, not the purpose of this bulletin to enter into a discussion of such applications, but to confine itself to the biochemical changes involved in the heating incident to sterilization.

Notwithstanding the fact that some of the results obtained by the investigators mentioned in the foregoing review, as well as some others, are contradictory, especially in regard to the effects of steam sterilization on crops, they seem to warrant the following conclusions:

By steam heating the physical, chemical, and physiological properties of the soils are more or less altered. The chemical changes consist in the increase in soluble matter in the heated soils. This is partially of an inorganic nature, potash and phosphoric acid being mainly determined, but the largest increase is in the organic matter rendered soluble. Ammonia may be formed by the reduction of the nitrates to nitrites and ammonia, but is especially formed from the decomposition of organic matter. Large amounts of nitrogenous matter are made soluble and apparently more available for plant use, and carbon dioxide is produced in large quantities.

By partial sterilization the larger phagocytic microorganisms, which are said to limit the activity of ammonifying bacteria in normal soils, are killed. The nitrifying bacteria do not grow on the freshly sterilized soils, there apparently being compounds formed which are of an inhibitory nature, but which disappear after a time. By complete sterilization all life in the soil is killed and reinoculation must be resorted to.

With regard to crop production in general, the sterilized soils seem to contain some substance which is decidedly injurious both to germination and to plant growth, particularly if calcium carbonate is not present in excess during the heating to prevent the forming of acids. After standing, and especially after planting for some time, these injurious effects weaken and finally disappear, with the result that the growth on the sterilized soil is greater than that on the normal soil, the plants showing large increases in dry weight and in the amounts of plant nutrients absorbed by them.

SCOPE OF THE INVESTIGATION.

In the foregoing enough of the early work has been presented to show that chemical changes occur in soils when heated as in the process of sterilization usually employed. The nature of the changes are not made clear, although a number of suggestions or hypotheses have been put forward. These concern themselves partly with the explanation of the increase in mineral constituents, due to altered absorption properties for these constituents or brought about by the greater hydrolysis or solubility of the minerals under the conditions of higher temperature. Nearly all of the investigators have particularly noticed the increase in soluble nitrogen and coincident with this the increase in soluble organic matter. It is these latter considerations that have been the source of most of the speculations to explain the increase and decrease, as the case may be, of plant growth on soils thus heated. These views are usually coupled with the biological idea which furnished the motive for the experiment.

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[1] Am. Florist, 9, 171 (1893)

[2] Ibid., 13, 721 (1898).

[3] Ohio Expt. Sta., Bul. 73, 231 (1896).

In no case has any definite compound been obtained, either as an end or intermediary product of the changes brought about by the heat, and the subject is left in the same state of indefinite generalization in which soil organic matter or humus found itself during the course of the last half century. In view of this lack of knowledge concerning the chemistry of soil organic matter itself, and its transformations under ordinary conditions, it is not to be expected that changes like the above could be clearly defined. As a consequence of this lack of knowledge concerning soil organic matter, these investigations had to confine themselves to the use of simple analytical methods, such as the determination of ammonia formed, the determination of the quantity of organic matter soluble in water or dilute acids, and the amount of nitrogen in organic combination contained therein. In addition to the above, there was also usually made a determination of total soluble solids and of phosphoric acid and potash, the other principal plant nutrients, besides the nitrogen.

The investigations of the last few years in this laboratory have brought with them an increasing knowledge of the nature of organic matter, especially with regard to the isolation and identification of specific chemical compounds from soils, so that the biochemical changes taking place in soil are becoming clear. In connection with these investigations methods for the recognition or isolation of specific chemical compounds have been developed. With such knowledge at hand, it seemed possible to go one step further and show the changes produced in soil organic matter in the process of sterilization by heat, and thus to be able to interpret the nature of such changes. By such an investigation, specific and definite knowledge concerning the organic constituents which actually exist in the heated soil and affect plant growth favorably or unfavorably, as the case may be, can be determined, and the nature of the interactions of such compounds in soil solutions interpreted. In the present bulletin are presented the results obtained along this line, which tend to throw a different light upon the subject and, moreover, to make clearer the changes which slowly take place in soils under normal conditions.

THE SOILS STUDIED.

The soils used in this investigation are two types of the Coastal Plains Province known as Elkton silt loam and Sassafras silt loam.[1] These two soils were collected from the same farm, about 4 miles east of Easton, Md., April 28, 1911. The samples taken were from several spots within a radius of 40 feet and were within 150 yards of each other, in adjoining fields.

Although these soils have the same geological origin, they differ rather widely in physical and chemical characteristics and in fertility. The largest areas of the Elkton soil are found in the peninsulas lying between estuaries. The central parts of most of these necks are nearly level, and the sluggish surface drainage, together with the character of the material, accounts for the formation of this type. Smaller areas are found in the uplands wherever similar conditions prevail.

The Elkton silt loam is associated with the Sassafras silt loam and is derived from the same kind of material. The differentiation is due mainly to drainage conditions. While the two soils are very distinct in color and in general agricultural value, the change from one to the other is frequently so gradual that it is difficult to draw an exact boundary. The samples taken are strictly typical.

ELKTON SILT LOAM.

The Elkton soil is a light-gray to almost white silt loam containing 82 per cent silt, 10.5 per cent clay, about 5.5 per cent fine sand, and practically no coarse sand. When in good tilth it is loose and floury, but when wet it has a tendency to run together and on drying to form a smooth hard surface, with minute cavities interspersed through it. The subsoil forms a compact stratum, very hard when dry, and when wet somewhat more plastic or sticky than the surface soil. Along the line of contact with rootlets there is a tendency to show a reddish-brown coloration, probably because of the oxidation of iron compounds by the roots. In places pieces of unrotted manure and plant residues were found, some of them retaining almost their original structure. Clover does not grow well on this soil, nor is it a good soil for corn, for the land is too cold and wet to be adapted to the latter crop. Wheat, however, is grown on it and compares rather favorably in yield with that grown on the Sassafras soil. The soil is acid and would be benefited by applications of lime and manure and by improvement in drainage conditions. However, the frequently unsatisfactory yields from well-drained lands indicate a poor structural condition and probably the presence of substances injurious to plant growth.[1]

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[1] Soil Survey of the Easton Area, Maryland. By H. H. Bennett, W. E. Tharp, W. S. Lyman, and H. L. Westover. Bureau of Soils, U. S. Dept. Agr. (1909).

SASSAFRAS SILT LOAM.

The Sassafras soil to a depth of 8 or 10 inches is, when moist, a friable yellow silt loam. It contains 72 per cent silt, 14.2 per cent clay, quite a little fine sand and some coarse sand, yields well to tillage, and the cultivated land has a soft loamy surface. The subsoil contains more clay than the soil and is rather compact, though between the depth of 15 to 30 inches it is somewhat granular. The drainage is good and the sandy substratum gives excellent underdrainage and prevents any undue accumulation of water where the surface is slightly depressed. The soil is well adapted to corn, wheat, hay, and clover.

SOME ANALYTICAL DATA.

For this investigation 1,000 pounds of each of the soils were collected. The Elkton soil was in clover, following wheat the year before, which had followed corn. The corn had yielded about 15 bushels to the acre, wheat about 20 bushels, and the clover was very poor. The soil was very moist and plastic and was collected from several spots upon which nothing was growing. The field was full of such spots. The Sassafras soil was collected in the next field, which had been plowed but not harrowed, and the soil was in excellent condition. Corn the preceding year had yielded 50 bushels, and the year before wheat had given about 20 bushels to the acre. The soils were sifted to remove any large stones or organic débris and then well mixed by repeated shoveling. The mechanical analyses were as follows:

TABLE I.—*Mechanical analyses.*

Soil type.	Fine gravel 2-1 mm.	Coarse sand 1-0.5 mm.	Medium sand 0.5-0.25 mm.	Fine sand 0.25-0.1 mm.	Very fine sand 0.1-0.05 mm.	Silt 0.05-0.005 mm.	Clay 0.005-0.00 mm.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Elkton silt loam	0.2	0.8	0.9	1.4	4.2	82.0	10.5
Sassafras silt loam	0.3	2.1	1.8	1.6	7.6	72.2	14.2

Analysis shows that these two samples contain practically the same quantity or organic matter, the Elkton 2.25 per cent and the Sassafras 2.24 per cent, the former contains 0.13 per cent of carbonates as carbon dioxide, and the latter only 0.03 per cent. The soils are both acid to litmus paper, the Sassafras being slightly the more acid of the two. In regard to their oxidizing and catalyzing power, that is, the decomposition of hydrogen peroxide, both are very weak, the Elkton showing none at all and the Sassafras only a little. They both contain practically the same percentage of total nitrogen. When the soils are boiled with hydrochloric acid and the different forms of nitrogen determined according to the method of Osborne and Harris[1], which was applied to soils by Shorey,[2] the soils show only trifling differences.

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[1] Examination of Soils for Organic Constituents, Especially Dihydroxystearic Acid, by Oswald Schreiner and Elbert C. Lathrop. Bul. 80. Bureau of Soils, U. S. Dept. Agr. (1911).

TABLE II.—*Different forms of nitrogen in Elkton silt loam and Sassafras silt loam.*

[Results expressed in per cents of total nitrogen in oven-dried soil.]

Form of nitrogen.	Elkton.	Sassafras.
	Per cent.	*Per cent.*
Per cent of total N in soils	0.0859	0.0869
N insoluble in HCl	8.17	8.92
N in HCl solution	91.83	91.08
N as NH_3 in solution	0.83	2.27
N as amides in solution	12.06	12.45
N as "humin" N in solution	18.96	19.63
N as diamino acids in solution	5.53	7.17
N as mono-amino, acids in solution	54.45	49.56

From the table it is apparent that the only difference worthy of mention is the fact that the Sassafras soil contains slightly more ammonia than does the Elkton soil, but this is much too small to account for the existing differences in fertility.

From the foregoing analytical data it is apparent that, in a general way, these two soils are very similar in their organic composition and that no methods of analysis, excepting the actual isolation of the various definite organic compounds which compose the organic matter, will show wherein the difference in their organic composition lies.

The methods of farm practice have been identical with these soils, and each has received the same kind of débris, manures, plant residues, etc., which by processes of decomposition form the organic matter of soils. If differences in the organic matter of these soils are shown to occur, they are due to different processes of decomposition taking place in the soils.

COMPARATIVE STUDY OF HEATED AND UNHEATED SOILS.

It is obvious that such an investigation as the present one derives its chief value from the fact that it is comparative for the heated and unheated soil of the same type. To attain this end, it is therefore necessary to know as much as possible concerning the nature of the organic matter in the normal or unheated soil so that the changes themselves, which take place as the result of heating, can be ascertained by direct comparison with the unheated soil as the control. While some analytical data have been obtained with these soils, the chief time and energy have been expended in the actual isolation or determination of compounds of definite chemical identity.

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[1] Jour. Am. Chem. Soc., **25**, 323 (1903).

[2] Agr. Invest. Hawaii in 1905, Rpt. Chemist., p. 34; see also Lathrop and Brown, Jour. Ind. Eng. Chem. **3**, 657 (1911).

METHOD OF HEATING.

For the purpose of heating the soils an autoclave, such as is in general use, was employed. The autoclave is of copper, so constructed that it may be automatically kept at two atmospheres of steam pressure for a given length of time. The soils were heated in 1-gallon stoneware jars placed in the autoclave in a metallic rack, the jars standing one above the other, the lower one being 4 or 5 inches above the bottom of the autoclave. These jars held approximately 10 pounds of soil. The soils were heated at 30 pounds pressure for three hours, at a temperature of about 135° C. The soils were treated with alkali just as soon as they had cooled to room temperature, so that only the changes caused by the immediate heating were under observation.

METHOD OF EXTRACTION.

Owing to the fact that only small quantities of organic matter are in these soils and also that not all of this organic matter can be extracted, large quantities of soil were used. Generally 40 to 50 pounds of soil, either heated or unheated, were extracted with 20 gallons of 2 per cent sodium hydroxide solution, the soil and solution being placed in a porcelain-lined, iron tilting kettle of a capacity of 30 gallons. This kettle is provided with a power-stirring device, with which the soil was stirred for seven hours. The stirrer was then removed and the soil allowed to settle overnight and sometimes for a longer time. The solution was then drawn off by means of a siphon. To the soil solution so obtained a suitable acid, depending on the ensuing procedure, was added until the solution was acid and the silt and so-called humus bodies were well flocculated. Providing the methods to be used would not be interfered with by the presence of large quantities of iron salts, the acid solution was then filtered through a filter press under pressure. If, however, iron salts would be objectionable, the solution was filtered through filter paper in the usual way. In either case after the filtered solution had been made exactly neutral with sodium hydroxide it was concentrated to a volume of 2 or 3 gallons in a vacuum pan, the temperature of the liquid not rising above 52° C. In this way large quantities of soil were easily and safely handled and a great deal of time saved.

No attempt was made to study the humus precipitate. The chief interest in the work centered about the nitrogen compounds, especially those rendered soluble by the heating of the soil. Such compounds would appear chiefly in the alkaline extract, and later in the acid filtrate from the humus precipitate.

The action of the weak alkaline solution is apparently to remove the resinous and similar material from the soil grains and to dissolve water-soluble material, as well as to form sodium salts with any of the acids which are present in the soil.

The acid filtrate, after neutralization and concentration, was used in the isolation of the various constituents that have been found in previous work, as well as any new compounds that might be encountered. A description of the methods by which the compounds were isolated from these soils will now be given.

METHODS OF ISOLATION AND IDENTIFICATION.

The purine bases and creatinine.—The original alkaline soil extract was made acid with sulphuric acid, and after filtering and concentrating was made quite alkaline with sodium hydroxide and the precipitate, consisting largely of the hydroxides of iron and aluminum, filtered from the solution. The bases were then precipitated in boiling solution with Fehling's solution and a little dextrose. The copper precipitate, after thorough washing, was suspended in water and decomposed with hydrogen sulphide, and, after the sulphides were removed by boiling and filtering, the solution was concentrated to about 150 c. c. Small portions of this solution were tested for the presence of the purine bases and for creatinine by the following color reactions: (1) The Xanthine reaction, which consists in the evaporation of the solution on the water bath with a little concentrated nitric acid, a yellow residue being obtained, which, on treatment with a drop of sodium hydroxide, gives a red color. On heating, this color changes to a purplish violet, but returns to red on cooling. This reaction is given by xanthine and guanine. (2) Weidel's reaction, which is given by xanthine and guanine, and consists in heating some of the solution with hydrochloric acid and nitric acid, or with hydrochloric acid and a chlorate, until gas ceases to be evolved, and then evaporating to dryness. When exposed to an atmosphere of ammonia this residue will turn pink if either of the bases is present. (3) Kossel's test, which is given by xanthine, hypoxanthine, adenine, and guanine, and consists in evaporating the solution with nitric acid and bromine water, when, on addition of a drop of sodium hydroxide, a red color is obtained. By these simple color reactions it is possible to tell in a general way which of the purine bases are present. Creatinine is indicated by (4) Jaffe's reaction, by which an orange color is developed in the solution on addition of sodium hydroxide and picric acid. (5) Weyl's reaction, giving an orange red color which changes to yellow on standing, produced by the addition to the solution of sodium hydroxide and sodium nitro-prusside. (6) Salkowski's test, which consists in adding acetic acid to the solution resulting from Weyl's test and heating, when a green color changing to blue is obtained.

If the three color reactions were positive for creatinine in the solution tested, zinc chloride and sodium acetate were added to a portion of the solution and allowed to stand for several days, when the characteristic crystals of creatinine zinc chloride were formed. These were separated on a porous plate, washed with a little cold water, boiled with some freshly precipitated lead hydroxide, filtered, and the filtrate concentrated to a small volume; on standing several hours crystals having the characteristic form, solubility, and color reactions of creatinine were obtained.

The remaining portion of the solution containing the purine bases was made ammoniacal and the bases precipitated with ammoniacal silver nitrate. The precipitate was filtered off, washed well with cold water, boiled with nitric acid (sp. gr. 1.10), and the solution filtered hot. On standing, if hypoxanthine, adenine or guanine were present they separated out in the form of their silver nitrate salts, while the xanthine remained in solution. These crystals were filtered off, decomposed in boiling water with hydrogen sulphide, and after the sulphides were removed ammonia was added to the solution, when guanine, if present, separated out, and was filtered off. The filtrate, which in one case contained both hypoxanthine and adenine, was treated with picric acid, when the adenine, if present, was precipitated as adenine picrate. This was filtered off, washed with a little cold water, and taken up in a solution of dilute hydrochloric acid, and the solution shaken out with ether made alkaline with sodium hydroxide, and the adenine precipitated as the copper salt, with Fehling's solution and dextrose. After treatment of this precipitate with hydrogen sulphide the adenine was further identified by the formation of its various characteristic salts—the hydrochloride, the nitrate, the dichromate, the picrate, and the platinum chloride salts.

The filtrate from the adenine picrate was treated with dilute sulphuric acid, extracted with benzene to remove the picric acid, and then precipitated in ammoniacal solution with ammoniacal silver nitrate solution. This precipitate after washing was decomposed with hydrogen sulphide and after freeing from sulphides and evaporating the hypoxanthine was identified by the formation of the hydrochloride, the nitrate, the platinum chloride, and the silver picrate salts.

The xanthine portion of the nitric-acid treatment was made alkaline with ammonia, and the resulting precipitate after washing was decomposed with hydrogen sulphide and the xanthine identified by color reactions and by the hydrochloride, the nitrate, and the crystalline form of the base itself.

Since guanine was found for the first time in soils during the course of this investigation, the methods used for its isolation and identification will be given in detail in another part of this bulletin.

Histidine and arginine.—The alkaline extract of the soil was made acid with sulphuric acid and filtered. After concentration the solution was made acid again with the same acid to about 5 per cent and filtered hot. After cooling phosphotungstic acid was added until precipitation ceased, when the solution and precipitate were allowed to stand for several days. The precipitate was then filtered off, washed with dilute sulphuric acid, and dissolved in a solution of three parts acetone and four parts water. Such a solution dissolves the phosphotungstic salts of the hexone bases. The solution was filtered from any insoluble matter and to the filtrate barium hydroxide was added to alkaline reaction, filtered, made slightly acid with nitric acid, and the acetone removed by heating. To the cooled solution silver nitrate was added until a drop of the solution caused a solution of barium hydroxide to turn yellow. Barium hydroxide was then added until an alkaline reaction persisted and precipitation ceased. This precipitate, which contains histidine, was filtered off and washed with dilute barium hydroxide solution, suspended in dilute sulphuric acid and decomposed with hydrogen sulphide. After the removal of the sulphides by boiling and filtration the solution was made slightly alkaline with barium hydroxide to precipitate the sulphuric acid and the barium removed with carbon dioxide. The solution was boiled, filtered, and evaporated to dryness. The residue was taken up with a little silver nitrate solution to which a drop of nitric acid had been added, and was filtered. To the filtrate ammonia was added until the precipitation was completed and the precipitate filtered off, washed, and decomposed on the filter with dilute hydrochloric acid. The solution so obtained was evaporated to small volume, when histidine in the form of the dichloride salt of histidine crystallized out in characteristic form.

To the filtrate from the precipitation of the histidine with barium hydroxide and silver nitrate, solid barium hydroxide was added and the precipitate, if any formed, was filtered off, washed with strong barium hydroxide solution and after suspension in dilute sulphuric acid, was decomposed with hydrogen sulphide. After freeing the solution from sulphides, barium hydroxide was added to remove the sulphuric acid, the barium removed with carbon dioxide, and the solution boiled and filtered. A portion of this solution was made neutral with nitric acid and evaporated to a small volume, when arginine, if present, crystallized out in the form of the neutral nitrate. To the remaining solution hydrochloric acid was added to neutrality, and on evaporation the hydrochloride of the base was obtained.

Cytosine.—For the isolation of this compound sulphuric acid was also used to acidify the alkaline extract from the soil. The concentrated neutral solution obtained from the vacuum pan was filtered, made acid with sulphuric acid, and an excess of mercuric sulphate solution added, and the whole allowed to stand for 24 hours. The precipitate which formed was filtered off, washed well, and after being suspended in water was decomposed with hydrogen sulphide. When the sulphides had been removed by boiling and filtration, the solution was evaporated to a small volume and allowed to stand for a time. A crystalline mass separated out, which was mixed with coloring matter and foreign material; consequently the solution was evaporated to dryness and extracted a number of times with absolute alcohol. The alcohol removed much of the coloring matter, and by repeated fractional crystallization from water a white compound was obtained which showed the characteristic crystalline structure and shiny appearance of cytosine. This compound was further identified by its solubility in water, alcohol, and ether, and the preparation of the platinum chloride, hydrochloride, picrate, and potassium-bismuth iodide salt.

Nucleic acid.—In this case acetic acid was used to acidify the alkaline soil extract, and the concentrated liquor was filtered hot. After cooling, a little more than an equal volume of 95 per cent alcohol was added to the solution and enough hydrochloric acid to make the solution acid to about 5 per cent. After standing several days the precipitate was filtered off, washed with water, and dissolved in dilute sodium hydroxide. The nucleic acid was again precipitated by the addition of sodium acetate, hydrochloric acid, and alcohol. The precipitate was filtered, washed, and dissolved in dilute ammonium hydroxide. To this solution lead acetate was added to complete precipitation, and the precipitate was filtered off and washed thoroughly with water. The precipitate was broken up, after suspension in a large volume of water, with sulphuric acid, care being taken to avoid any excess of acid. From this solution the nucleic acid was again precipitated with sodium acetate, hydrochloric acid, and alcohol, and the precipitate after thorough washing on the filter was dried. The compound so obtained was fairly light in color and was amorphous. A portion of it was boiled with concentrated hydrochloric acid and tested for pentoses with the phloroglucin and orcin tests, which showed their presence. Another portion was evaporated with magnesium nitrate, ignited, and the residue taken up with hydrochloric acid. This solution gave tests for phosphates both with ammonium molybdate and with magnesia mixture. The remainder of the substance was boiled with hydrochloric acid, made alkaline with sodium hydroxide, and the purine bases present precipitated with Fehling's solution, the precipitate being treated as described for the isolation of the purine bases. From this solution the Xanthine test was obtained, but the bases were present in such small quantities that their individual identity could not be ascertained.

Dihydroxystearic acid.—To acidify the alkaline extract in this case sulphuric acid was used. To the concentrated solution obtained later, sulphuric acid was again added to strong acid reaction and the solution filtered hot. After cooling, the solution was shaken out twice with ether. The ether solution was quite strongly colored, and it was found that if this solution were shaken out with a saturated solution of sodium bisulphite the bisulphite solution absorbed almost all the color. The ether solution was then evaporated over a small quantity of water, about 100 c. c., and this solution boiled and filtered through a filter paper wet with hot water. On standing the dihydroxystearic acid, if present, crystallized out and on drying on a porous plate was white and melted at 99° C.

An unidentified aldehyde.—The bisulphite solution from the above extraction was made acid with sulphuric acid and the sulphur dioxide removed by heating on the steam bath. This solution on extraction with ether and evaporation of the ether over water gave an oily residue which was slightly soluble in water. The water solution gave a violet color when a dilute solution of ferric chloride was added to a portion of it, and also gave a slight test for aldehydes with the fuchsine aldehyde reagent. Attempts to make either a phenylhydrazine, hydroxylamine, or semicarbizid compound failed. The aldehyde acts somewhat like salicylic aldehyde, but the amount obtained was too small to enable identification.

Pentosans, pentose sugars, and xylose.—Acetic acid was used to acidify the alkaline soil extract, and after the solution had been filtered through paper it was made neutral with sodium hydroxide and again filtered to remove the precipitate of aluminum, etc. To this solution neutral lead acetate was added, the solution stirred several times, and the lead precipitate allowed to settle for several days. The clear solution above the precipitate was siphoned off, made quite alkaline with ammonia, and allowed to stand a day or two. The precipitate obtained was separated first by siphoning off the supernatant liquid and then by filtering. It was washed well with water, suspended in water, and decomposed with hydrogen sulphide. The resulting solution after removal of the sulphides was concentrated to a small volume and on cooling was added to three volumes of alcohol. On standing some time the pentosans settled out as a gummy precipitate and were filtered off and washed. Some of the precipitate was boiled with hydrochloric acid and tested with phloroglucin and orcin. The remainder of the precipitate was boiled with dilute sulphuric acid, the acid removed with barium hydroxide, and the barium with carbon dioxide. To a portion of this solution cadmium carbonate and bromine water were added, and the resulting double salt of cadmium xylonate and cadmium bromide was obtained in characteristic crystalline form. An ozazone was also prepared, but could not be obtained pure enough for a melting point test.

Pentose sugars were determined in the filtrate from the pentosan precipitate by evaporating off the alcohol and making the two tests with hydrochloric acid, phloroglucin, and orcin. Attempts were made to isolate these sugars, but they were unsuccessful.

ISOLATION AND IDENTIFICATION OF GUANINE.

When ammonia was added to the solution containing hypoxanthine, adenine, and guanine, as already described, there was formed, in the case of the Sassafras heated soil, a gelatinous precipitate. This precipitate was filtered off, washed with a little cold water, and then dissolved in warm dilute hydrochloric acid. On evaporating a little of this solution to dryness with nitric acid and placing the dish containing the residue in an atmosphere of ammonia a pink color was developed. The solution remaining was divided into two portions. To the first portion, which had been previously warmed, a cold saturated solution of picric acid was added, when the picrate described by Capranica[1] separated out in crystalline form, which under the microscope appeared as pencil-shaped, fernlike tufts of orange yellow needles. They were very insoluble in water, and on drying took on a feltlike appearance with a silky luster, and became golden yellow in color. On heating they became orange red and began to decompose at 190° C.

To the other portion a solution of potassium dichromate was added, and on standing the dichromate salt described by Wulff[2] separated out in large, well-formed, bright orange colored, elongated, four-sided prisms with truncated ends. This salt was allowed to dry and was then heated to about 100° C., when it lost water and turned a dark violet color.

By the method of obtaining this base, its solubility in water, ammonium hydroxide, and hydrochloric acid; the solubility of the silver nitrate salt in nitric acid of specific gravity 1.10; the various color reactions, and the two characteristic salts, the picrate and the dichromate, the identity of the compound is established as guanine.

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[1] Zeit. physiol. Chem., 4, 233 (1880).

[2] Ber. deutsch. chem. Ges., 30, 2241 (1897).

COMPOUNDS ISOLATED FROM THE HEATED AND THE UNHEATED SOILS.

The procedure followed in carrying out this work and isolating or identifying the organic constituents in the unheated and heated soils has been briefly described in the foregoing. The results of this part of the investigation are concisely given in the following table:

TABLE III.—*Organic compounds isolated from heated and unheated soils.*

Elkton silt loam.		Sassafras silt loam.	
Unheated.	Heated.	Unheated.	Heated.
Nucleic acid.	Nucleic acid.	Nucleic acid.	Nucleic acid.
Xanthine.	Xanthine.	——	Xanthine.
——	Hypoxanthine.	Hypoxanthine.	Hypoxanthine.
Adenine.	Adenine.	——	——
——	——	——	Guanine.
——	Cytosine.	——	Cytosine.
Pentose sugar.	Pentose sugar.	Pentose sugar.	Pentose sugar.
Pentosans.[1]	Pentosans.	Pentosans.	Pentosans.
Histidine.	Histidine.	Histidine.	Histidine.
——	——	——	Arginine.
Creatinine.	Creatinine.	Creatinine.	Creatinine.
Dihydroxystearic acid.	Dihydroxystearic acid.	——	Dihydroxystearic acid.
——	Unidentified aldehyde.	——	Unidentified aldehyde.

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[1] From the pentosans of this soil xylose was obtained, showing that it was, at least in part, xylan.

In harmony with other investigators, the total amount of water soluble solids was increased by the heating. The soils when treated with four parts of water showed, by the bridge method, the following content in total solids: The normal Elkton soil, 184; the heated Elkton soil, 336; the normal Sassafras, 151; the heated Sassafras, 270 parts per million of dry soil. It will be noticed that the poorer soil showed the higher content of total solids under both heated and unheated conditions. No further examination of the saline material was made. By heating, the acidity of both soils was increased. It should be noted, however, that ammonia and amines were formed by the process of heating, as was indicated by the fishy odor upon adding the alkali in the process of extraction.

The results in Table III show only whether the organic compound was present or not. While no quantitative methods for the separation of these compounds from soils exist, owing to a great variety of difficulties which can not be entered into here, still in the work it was possible to distinguish between very small amounts and larger ones, and these differences are of interest and in a few instances highly instructive.

As seen from the table, the nucleic acid was found in both soils, in the heated as well as in the unheated samples. However, from the heated samples less nucleic acid was obtained than from the unheated samples, which fact is in harmony with the increase in nucleic acid decomposition products.

Xanthine was found in both heated and unheated Elkton soil, but in larger quantity in the heated soil. In the case of the Sassafras soil it was found only after heating.

Hypoxanthine was not found in the Elkton soil, but after heating a small quantity was obtained. The Sassafras soil contained this constituent, but its quantity was much increased by heating the soil.

Adenine was found in small quantity in the Elkton soil, but was not obtained from the Sassafras. Heating effected no change in either case.

Guanine was found only in the Sassafras soil after heating and is of especial interest, since this is the first time it has been encountered in soil.

Cytosine is likewise a decomposition product of nucleic acids, and it is interesting to note that it was found only in the heated samples of both soils. It was obtained in much larger quantities in the case of the heated Sassafras soil than in the heated Elkton soil.

Pentose sugar was indicated in both soils, heated and unheated. Pentose sugar reactions have been given, however, by every soil tested in this laboratory, which is also the case with pentosans.

Histidine occurs in both soils, and a slight increase was noticed as the effect of the heat.

Arginine, on the other hand, was found only in the heated Sassafras.

Creatinine was present in all cases.

The unidentified aldehyde in the above table, as has already been mentioned, is an aldehyde with a benzene ring. It was found in small quantities, but only in the heated soils, and may, therefore, be assumed to be formed during the process of heating.

Dihydroxystearic acid occurs in the Elkton soil, but not in the Sassafras soil, as has been reported in a special study of the distribution of this compound in soils, presented in a former bulletin.[1] The present samples of the two soils, from the same fields but collected two years later, showed this same relationship, indicating that the compound is a rather constant constituent of the Elkton soil under the field conditions to which it has been subject. The heated Elkton soil showed an increase in the quantity of dihydroxystearic acid. While no dihydroxystearic acid exists in the Sassafras soil under normal conditions, it is significant that after heating, a very considerable quantity was isolated—a quantity even larger than that found in the unheated Elkton soil and fully as large as in the heated Elkton soil.

CHEMICAL CHANGES INCIDENT TO THE HEATING OF SOILS.

While it is not the purpose to discuss here fully all the changes which are involved in protein decomposition, it is, however, necessary to consider certain phases of the subject related to this investigation, so that a clear conception of the changes observed in the course of this investigation may be obtained.

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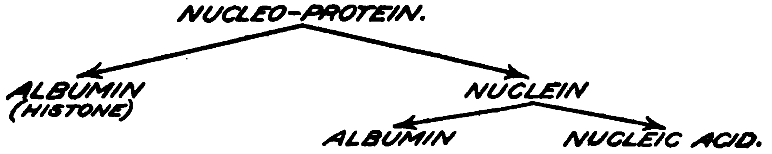
[1] Bul. 80, Bureau of Soils, U. S. Dept. Agr. (1911).

There get into the soil continually such complex organic compounds as proteins, lecithins, nucleic acids, nucleo-proteins. While the final products of decomposition of these are no doubt such simple combinations or elements as carbon dioxide, marsh gas, ammonia, nitrogen, hydrogen, these products are arrived at by certain definite and fairly well understood stages of degradation. Depending on the factors present under various soil conditions, this process may be a rapid one, a slow one, or one entirely arrested at certain stages. The latter condition may be due to the fact that some of the factors necessary to accomplish the next change in the process of degradation are absent.

NUCLEO-PROTEIN DEGRADATION.

Nucleo-proteins are perhaps the most complex of the compounds which enter the soil. They are common constituents of plants, animals, bacteria, and molds, and occur, therefore, wherever these live and die. It will be well to trace such a complex compound through the chemical changes which it suffers by decomposition. Lilienfeld[1] has expressed the decomposition of a nucleo-protein by the following schematic representation:



The products then are albumin or protein and nucleic acid. Protein material has not been isolated as such from soils, but that it is present is indicated by the production of its decomposition products, as well as by the occurrence of these products in soils under normal conditions. The isolation of nucleic acid from soils, on the other hand, has been accomplished.

NUCLEIC-ACID DEGRADATION.

The nucleic acid is still a very complex compound and on decomposition yields a large number of compounds of somewhat less complicated nature. The name nucleic acid is a class name, covering a large number of compounds composed of carbon, hydrogen, oxygen, nitrogen, and phosphorus. The acid occurs in plant and animal cells and has been isolated from soils.[2]

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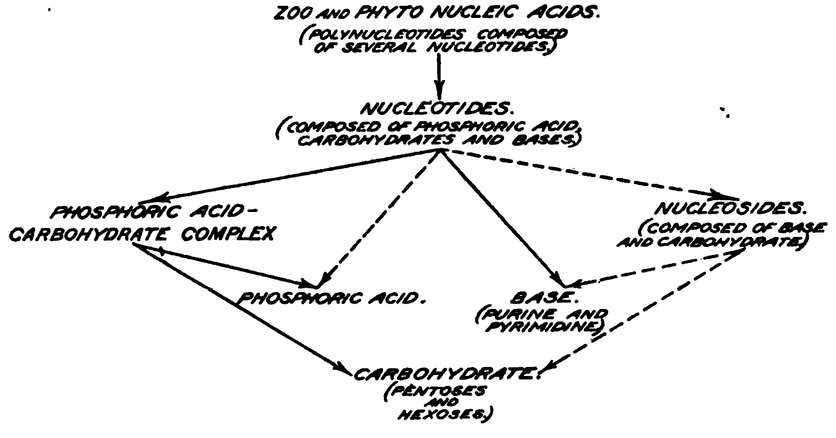
[1] Arch. f. (Anat. u.) Physiol., 1892, p. 128.

[2] Shorey, Science, 35, 390 (1911); Bul. 88, Bureau of Soils, U. S. Dept. of Agr., 1912.

The proportion of the above elements in nucleic acid differs, depending upon the source of the nucleic acid, and this is due to the fact that the unit substances composing it are different. Thus, for instance, the nucleic acid from yeast, according to Herlant,[1] has the composition $C_{36}H_{48}O_{30}N_{14}P_4$, that from salmon, according to Schmiedeberg,[2] the composition $C_{40}H_{52}O_{25}N_{14}P_4$, and that from wheat, according to Osborne and Harris,[3] $C_{41}H_{61}O_{31}N_{16}P_4$.

The constitution of these complex nucleic acids is unknown, but the constitution of most of the dissociation products is known. As above mentioned, these dissociation products vary according to the source of the nucleic acid. These degradation products are: Phosphoric acid, which is always found; carbohydrates, which are always found; laevulinic acid, which is sometimes found; pyrimidine derivatives, which are always found; and purine bases, which are also always found. According to which pyrimidine base, thymine, cytosine, or uracil is present, or according to which purine base, guanine, adenine, xanthine, or hypoxanthine is present, the composition of the acid varies. Since several of these compounds are present at the same time, a great variety of combinations is possible.

While the simpler end products of nucleic acid are as above mentioned, the dissolution of the nucleic acid molecule does not take place in one step. There are several intermediary products or combinations of the above-mentioned final products which have definite chemical and physical identity. The researches of Levene and his school have served to clear up to a large extent the nature of these intermediary products. The steps in the disintegration of the plant and animal nucleic acids can perhaps be best made clear by the following schematic representation:


ZOO AND PHYTO NUCLEIC ACIDS.
(POLYNUCLEOTIDES COMPOSED OF SEVERAL NUCLEOTIDES.)
NUCLEOTIDES.
(COMPOSED OF PHOSPHORIC ACID, CARBOHYDRATES AND BASES.)
PHOSPHORIC ACID-CARBOHYDRATE COMPLEX
NUCLEOSIDES.
(COMPOSED OF BASE AND CARBOHYDRATE.)
PHOSPHORIC ACID.
BASE.
(PURINE AND PYRIMIDINE.)
CARBOHYDRATE.
(PENTOSES AND HEXOSES.)

The complex zoo or phyto nucleic acids, for instance those from wheat, yeast, salmon, are composed of simpler nucleic acids which Levene has called nucleotides. The nucleotides are composed of phosphoric acid, carbohydrates, and bases, either purine or pyrimidine.

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[1] Arch. exp. Path., 44, 148 (1900). [2] Arch. exp. Path., 43, 57 (1899). [3] Zeit. physiol. Chem., 36, 85 (1902).

Several of these nucleotides have been isolated, for instance, inosinic acid,[1] guanylic acid,[2] cytidin-phosphoric acid,[3] uridin-phosphoric acid,[3] thymohexose-phosphoric acid.[4] On further decomposition the nucleotide can part with its phosphoric acid on the one hand and yield a complex consisting of the base and the carbodydrate, designated as nucleoside in the diagram, and on the other hand it can part with the base, and leave a complex consisting of phosphoric acid and the carbohydrate. Of the nucleosides, a considerable number are known, inosin,[4] guanosin,[4] adenosin,[4] xanthosin,[5] which are, respectively, hypoxanthine, guanine, adenine, and xanthine combined with the carbohydrate. Further, from the nucleotides, cytidin- and uridin-phosphoric acids, the nucleosides cytidin [5] and uridin [5] are obtained which consist, respectively, of combinations of cytosine and uracil with carbohydrate. Several of these compounds are well-defined crystalline bodies and form salts of the same type as the base contained in them. A definite carbohydrate-phosphoric acid complex has also been isolated and a crystalline barium salt obtained. This is the d-ribose phosphoric acid[6] obtained by Levene and Jacobs. All of these various products can then be broken down into the phosphoric acid, carbohydrate, and base, purine or pyrimidine.

TRANSFORMATION OF THE BASES.

The purine and also the pyrimidine derivatives are capable of being changed one into the other, by both chemical and biochemical agencies. Nitrous acid has been used to effect such changes. In this manner, Fischer[7] changed guanine into xanthine, Kossel[8] changed adenine into hypoxanthine, and Kossel and Steudel[9] changed cytosine into uracil. Similarly Levene[10] has changed the complexes guanosin, adenosin, and cytidin into xanthosin, inosin, and uridin, respectively.

These changes produced by strictly chemical means are paralleled by the biochemical changes induced by bacteria and enzymes. It was shown by Schittenhelm and Schröter[11] that putrefactive bacteria, especially coli bacillus, were able to convert adenine and guanine into hypoxanthine and xanthine. They also show that the bacteria have the power of splitting down the nucleic acid itself. This change of nucleic acid is also brought about by certain enzymes which have been called nucleases, such as erepsin.[12]

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[1] Levene and Jacobs, Ber. deutsch. chem. Ges., 44, 746 (1911).

[2] Levene and Jacobs, Biochem. Zeit., 28, 127 (1910).

[3] Levene, Abderhaltens Biochem. Arbeitsm., V, 489 (1911).

[4] Levene, Abderhaltens Biochem. Arbeitsm., II, 605 (1910).

[5] Levene, Abderhalten, Biochem. Arbeitsm., V, 489 (1911).

[6] Ber. deutsch. chem. Ges., 41, 2703 (1908).

[7] Ann. Chem. Pharm., 215, 253 (1882).

[8] Zeit. physiol. Chem., 10, 258 (1886).

[9] Zeit. physiol. Chem., 88, 54 (1903).

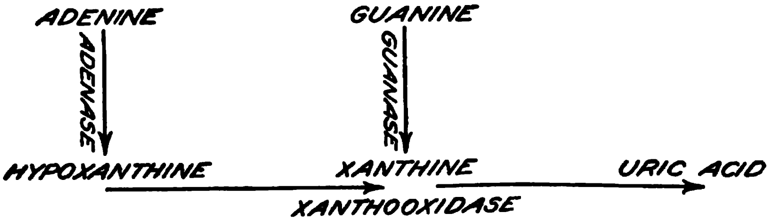
[10] Abderhaldens, Biochem. Arbeitsm., V, 489 (1911).

[11] Zeit. physiol. Chem., 41, 284 (1904).

[12] Nakayama, Zeit. physiol. Chem., 41, 348 (1904); Iwanoff, Zeit. physiol. Chem., 39, 31, (1903); Sachs, "Ist die Nulslease mit dem Trypsin identisch." Diss. Heidelberg, 1905.

Schittenhelm[1] has shown the presence of an amidase in the pressed juice of lupine seeds capable of converting guanine into xanthine.

Burion[2] showed that enzymes were capable of oxidizing xanthine and hypoxanthine into uric acid. The existence in animal tissues of amidases capable of causing the conversion of the amido-purines (guanine and adenine) into the oxypurines (xanthine and hypoxanthine) has been repeatedly demonstrated. These changes produced by the various ferments are perhaps best shown by the diagram given by Jones and Austrian.[3]



The above exposition of the changes involved in the degradation of nucleic acid makes clear the fact that this operation occurs in many stages. Also that some of these intermediary as well as final products are capable of being transformed one into the other. This degradation and transformation can be brought about in many different ways: By chemical means, such as the action of acids, alkalies, and steam under pressure; by microorganisms; and by enzymes. The fact that such changes have been worked out in other lines of research enables us to interpret the changes observed in soils when heated, as well as to explain differences observed between soils not heated.

CHEMICAL CHANGES IN THE NUCLEIC ACIDS IN THE SOILS.

Applying these principles to the interpretation of the results obtained by heating the Elkton and Sassafras soils, it becomes evident at once that hydrolysis of the nucleic acids in these soils has taken place. This is evidenced by the fact that in each case there was a diminution in the amount of nucleic acid obtained from the soils, and by the increase, both in quantity and in number, of the nucleic acid bases.

In the Elkton soil unheated, xanthine and adenine were found; on heating, the amount of xanthine increased, adenine was found as before, and in addition hypoxanthine appeared. The hypoxanthine has been formed from a nucleotide or a nucleoside containing this base. The fact that it did not appear in the unheated soil may be due to an arrested decomposition of its antecedents or to the fact that it is changed by enzymes or microorganisms into xanthine or lower nitrogenous compounds. Similarly, the appearance of cytosine in the heated soil has undoubtedly arisen from the same cause, namely, the action of the heating on antecedents containing it.

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[1] Zeit. physiol. Chem., 63, 289 (1909).

[2] Zeit. physiol, Chem., 43, 497 (1905).

[3] Jour. Biol. Chem., 3, 228 (1907).

In the Sassafras soil the changes are even more definite. In the unheated soil the only nucleic-acid base found was hypoxanthine, but after heating there appeared xanthine, guanine, and cytosine, as well as a larger quantity of the hypoxanthine. The absence of xanthine and guanine in the unheated soil would seem to indicate that their antecedents are not subject to further decomposition under these soil conditions or else that they are rapidly changed to uric acid, urea, ammonia, etc., under the existing soil conditions.

BIOCHEMICAL DIFFERENCES BETWEEN THE SOILS.

These two soils, as already mentioned, have had the same general field treatment and have received the same kind of organic matter in the form of manures and crop débris, so that the nucleo-proteins, nucleins, nucleic acids, etc., which have entered these soils have been practically the same. The different results in the heated as well as in the unheated soil can only show that the decompositions occurring normally under the two different soil environments are biochemically different. It has been repeatedly emphasized in the publications from this laboratory that the organic matter of different soils is different, and in the present instance not only is this clearly shown, but it is pointed out that this difference is brought about by biochemical factors.

One difference between the two soils is found in the fact that the Elkton soil contains no antecedent compound which will yield guanine by heating. This fact may be explained by the assumption that the guanine antecedent, possibly guanosin, is changed to a xanthine antecedent. Color is lent to this assumption by the fact that xanthine is found in both the unheated and heated soil. On the other hand, guanine as well as xanthine is found in the heated Sassafras soil, whereas neither is found in the unheated.

Another difference lies in the adenine. This is found in the Elkton soil and not in the Sassafras, and any antecedent bodies seem also absent from the latter soil, since it is not produced by heating. Hypoxanthine, on the other hand, into which adenine or its antecedents may change, is absent from Elkton but present in Sassafras.

Cytosine antecedents are present in both soils. The fact that cytosine itself is not found in the unheated soils may again be due to permanency of the antecedent under both soil conditions or else to the presence of factors, either chemical or biochemical, which transform it into uracil. Whether uracil exists in these soils or, in fact, any other soil can not be experimentally determined at present, owing to lack of characteristic derivatives or properties of uracil, although it seems probable that it must exist at least under certain conditions.

PROTEIN DEGRADATION.

The nucleic acid decomposition has been followed in the preceding sections from its combination in a nucleo-protein to its end products. The albumins or proteins which split off in the early stages, as well as proteins which exist as such in plant and animal tissues, are, if anything, more complex than the nucleic acid, and the intermediate products between protein, on the one hand, and the final products of complete hydrolysis, on the other, are less clearly defined than in the case of the nucleic acid products. It is certain, however, that there are such products. The final products are well known and their properties clearly defined.

Two of these final products of protein hydrolysis appear in the present investigation. These are arginine and histidine. The latter was found in both soils, unheated and heated, but was found in greater quantity in the heated soil. Arginine, on the other hand, was found only in the heated Sassafras soil. There is present, therefore, in the Sassafras soil a protein complex which acts as the antecedent of arginine. The question then remains, Why is arginine absent from the unheated soil, and also why is this antecedent body absent from the Elkton soil? Arginine, although a very common primary dissociation product of proteins, has, nevertheless, only been found in two other soils. This is rather peculiar in view of the fact that its close associate, histidine, has been found very often, a fact which is best explained on the supposition that arginine is very susceptible to changes through biochemical influences. For instance, Kiesel[1] found that the arginine in the juice of the green sprouts of lupine disappeared in the course of a four weeks' autolysis. It seems probable that its susceptibility to change is the reason of its nonappearance in the normal Sassafras soil. In regard to the second part of the question, as to the absence of any direct antecedent body, no very definite statement can be made, but it seems reasonable that, since there is protein material still in the soil, the change has not proceeded to a stage where arginine could be produced by such a procedure as was here employed. In other words, the biological factors in the Sassafras soil were such as to furnish an intermediary product which was dissociable by heat. From this is would again appear that the biochemical factors in the two soils are somewhat dissimilar under field conditions.

Concerning creatinine, nothing definite is known as to its antecedent compounds and no special lesson can be learned from the occurrence of this constituent in these soils. The same may be said of pentose sugars and pentosans.

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[1] Zeit. physiol. Chem., **60**, 460 (1909).

BENEFICIAL EFFECTS OF THE ORGANIC NITROGENOUS COMPOUNDS FORMED.

The compounds considered thus far, taken as a whole, show an increase in the heated soil, both in quantity and in number. This is in harmony with the often observed analytical fact that the heating produces an increase in soluble nitrogenous material. These results show the nature of the compounds thus made soluble. It remains to discuss the effect of such compounds on plant growth. Nearly all of these soil constituents have been studied in regard to their effect on plant growth and the results reported in an earlier bulletin.[1] Among those tested were nucleic acid, hypoxanthine, xanthine, guanine, histidine, arginine, and creatinine. All of these were shown to be decidedly beneficial to the growth of wheat seedlings.

Take, for instance, hypoxanthine. The effect of this soil constituent was studied in solutions containing many different ratios of fertilizer elements. The effect of the hypoxanthine was very marked in those cultures containing phosphate and potash but no nitrate. The average increase in growth in these cultures as a result of the presence of 100 parts per million of hypoxanthine was 41 per cent. When nitrate was also present, the increase due to hypoxanthine was not so great, but is was shown that in the presence of hypoxanthine less nitrate was consumed by the plants. All the other compounds mentioned above behaved in this same general way. In the absence of nitrate, nucleic acid gave an increase of 74 per cent, histidine gave an increase of 30 per cent, arginine an increase of 33 per cent, and creatinine an increase of 36 per cent. Guanine and xanthine were not tested in this same comprehensive manner, but the results show conclusively that they, too, are beneficial.

In view of these facts the cause of the increased productiveness of heated soils would seem to be explained by an increase in beneficial, readily and directly assimilable organic soil constituents. But what of the undoubted fact that some soils when heated show a harmful rather than beneficial effect on plant growth, especially on germination and the early stages of growth?

HARMFUL EFFECTS OF HEATED SOIL.

The heated and unheated soils, as well as water extracts from them, were tested for their effects on plant growth. The soil test was made in paraffined wire pots in the usual manner. The wheat seedlings grew from July 6 to July 21, 1911. The results of this test were as shown in Table IV.

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[1] "Nitrogenous Soil Constituents and Their Bearing on Soil Fertility," by Oswald Schreiner and J. J. Skinner, Bul. No. 87, Bureau of Soils, U. S. Dept. of Agr. (1912).

TABLE IV.—*Plant growth on heated and unheated soils.*

Soil and treatment.	Green weight.	Relative growth.
	Grams.	
Sassafras silt loam	2.525	100
Sassafras silt loam, heated	1.070	42
Elkton silt loam	2.043	81
Elkton silt loam, heated	1.820	72

In harmony with the field experience on these soils, the Sassafras is the better soil, the Elkton giving in this case only 81 per cent of the growth obtained in the Sassafras soil. The heating, however, had a bad effect on both soils, by far the greater depression occurring in the normally better soil. All of this is of course surprising in view of the fact that more nitrogen compounds, shown to be in themselves beneficial, are liberated by heat in both soils, and particularly in the Sassafras soil. It is obvious that the chemical changes so far discussed do not explain this observed fact in regard to plant growth, and it is further obvious that some harmful compounds are produced in both cases, and apparently to the greatest extent in the Sassafras soil, in addition to the beneficial compounds already discussed. The depressed plant growth is also shown by the water extract from such heated soils as compared with the unheated, although, as might be expected, the effect is not so marked. The proportion of water and soil used was 4 of water in 1 of soil, and the solution culture made in the manner usual in this laboratory. The wheat seedlings grew from April 9 to April 19, 1912. The results are given in Table V.

TABLE V.—*Plant growth on extracts from heated and unheated soils.*

Soil extract.	Green weight.	Relative growth.
	Grams.	
Sassafras silt loam	5.100	100
Sassafras silt loam, heated	4.200	82
Elkton silt loam	4.800	94
Elkton silt loam, heated	4.600	90

The effects of the soil extracts are in the same order as the effects of the soils in the preceding table, the Sassafras heated being again the poorest medium for plant growth.

PRESENCE OF DIHYDROXYSTEARIC ACID IN THE ELKTON SOIL.

The lower productivity of the Elkton soil in the field and in laboratory experiments has been repeatedly noticed during several investigations conducted by this bureau. According to the latest publication[1] on this subject, this lower productivity may be explained, in part at least, by the presence in this soil of dihydroxystearic acid. This compound has been isolated from a number of unproductive soils, and its relation to infertility has thus been strongly indicated. Experiments with the compound itself have shown it to be very toxic to wheat seedlings, causing a diminution in growth, stunted root development with darkened root tips, often bent into hook-like forms, and diminishing very markedly the absorption of nutrients by the plants.

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[1] Bul. 80, already cited.

As before, the dihydroxystearic acid was found in this sample of Elkton soil and absent from the Sassafras soil. The dihydroxystearic acid is fairly easily destroyed or altered by oxidation. The influence of nitrate, which stimulates root oxidation,[1] and lime, which has the same effect on root oxidation, and probably also in the soil itself, since organic matter always disappears under its influence, have been shown to diminish the toxicity of the dihydroxystearic acid.[2] This remedial effect of lime and nitrate is also shown in the following cultural test, where several fertilizer elements were used, the rate per acre being 50 pounds of P_2O_5, K_2O, and NH_3. The lime was at the rate of 1 ton per acre.

TABLE VI.—*Effect of fertilizers on Elkton and Sassafras soils.*

Treatment.	Elkton.		Sassafras.	
	Green weight.	Relative growth.	Green weight.	Relative growth.
	Grams.		*Grams.*	
Check, nothing added	2.043	100	2.525	100
Phosphate	2.120	104	3.530	139
Potash	3.200	157	3.390	134
Nitrate	3.310	162	2.960	117
Phosphate, potash, and nitrate	3.225	158	3.790	150
Lime	3.272	160	2.240	88
Lime and nitrate	3.700	181	3.250	128
Lime and phosphate, potash, and nitrate	3.700	181	3.250	128

It is not the purpose here to discuss fully all the details of this test, but simply to call attention to the different relative responses of the two soils in regard to the fertilizers and lime. Both soils were acid in their reaction to litmus paper. The Elkton responds readily to lime, the Sassafras does not. The Elkton does not respond to acid phosphate; the Sassafras shows next to the largest increase produced, the largest being the complete fertilizer. In the case of the Elkton the larger increases were those in which nitrate and particularly nitrate and lime were used, which was not the case with the other soil. These facts are most strikingly shown by a comparison of the relative growth figures in the table.

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[1] The Rôle of Oxidation in Soil Fertility, by Oswald Schreiner and Howard S. Reed, Bul. 56, Bureau of Soils, U. S. Dept. Agr. (1909).

[2] Some Effects of a Harmful Organic Soil Constituent, by Oswald Schreiner and J. J. Skinner, Bul. 70, Bureau of Soils, U. S. Dept. Agr. (1910).

INFLUENCE OF HEATING THE SOIL ON DIHYDROXYSTEARIC ACID.

Since this compound is apparently easily attacked, it was thought that heating the soil might cause a diminution of the quantity present, or perhaps the entire disappearance of the compound. It soon became evident, however, that on heating the Elkton soil the quantity of this compound increased rather than decreased. The plant tests in the water solution bore out this fact of an increase in the harmful constituent. The water solution of the heated Sassafras soil showed even greater toxicity than the heated or unheated Elkton soil.

This, as stated above, points to the generation of a toxic compound by the process of heating. Dihydroxystearic acid appears in the normal Elkton soil, which, as mentioned, has had the same sort of organic matter introduced into it as had the Sassafras soil, but which has been subject to different biochemical changes. The toxic substances generated by heat in the Sassafras soil should bear some relation chemically to the one found normally in the Elkton soil. Examination of the heated Sassafras soil showed the toxic compound to be identical with that in the Elkton soil, namely, dihydroxystearic acid; furthermore, this compound was obtained in even larger amount from the heated Sassafras than was obtained from the Elkton soil, either heated or unheated.

The production of this harmful compound, although this may not be the only one produced on heating, explains in itself the decrease in the fertility of the heated soil.

What the antecedent body in the Sassafras soil under field conditions may be is not known. Certain it is, however, that dihydroxystearic acid, as such, is not found in the Sassafras soil until after heating. The antecedent is probably the same in both soils, but under the influence of the different biochemical factors existing in the Elkton soil this antecedent compound is so changed that the harmful influence of the dihydroxystearic acid shows itself.

BALANCE BETWEEN BENEFICIAL AND HARMFUL FACTORS IN SOILS.

In the foregoing it has been shown that beneficial compounds have been increased by heating, but simultaneously with this increase there has been a production of harmful compounds. The effect on plant growth is naturally the mean of these two influences, and the full beneficial effects can not show themselves until the harmful compound has been eliminated by oxidation, reduction, cultural treatment, or other means. Similarly the full harmful effect of a compound is not attained in the presence of beneficial compounds. This state of affairs is, however, not an unusual one confined to heated soils, but is found in soils under normal field conditions. The soils under consideration are an excellent illustration of this point. The Elkton soil contains beneficial constituents, but also contains dihydroxystearic acid, a harmful constituent. The plant growth upon it depends upon the balance of these two opposing factors; when one is decreased the other gains the ascendency. In the other soil—that is, the Sassafras—this harmful compound is absent or at a minimum under field conditions, and the beneficial compounds exert their full effect. Any change in soil condition may bring about a change in this balance of the opposing forces, so that the soil becomes temporarily or permanently more fertile or less fertile, as the case may be. The heating of the soil brings about a very rapid or sudden change in this respect, with the result that, even though beneficial compounds are liberated in this fertile soil, the production of the harmful compound more than overbalances them, with the result that the plant growth drops to 42 per cent of the normal. In the case of the Elkton soil, which already contained this compound, the effect of the heating was also to increase the beneficial compounds and only slightly increase the harmful compound, so that the net result was that crop growth was only depressed to 89 per cent of the normal. In other words, the balance was more disturbed in the case of the Sassafras soil than in the case of the Elkton. The effect of addition of fertilizers to the two soils was to alter this balance, and to alter it most in the case of the Elkton soil. Especially is this true in regard to the effect of lime and of nitrates in the two soils. Cultural methods or crop rotation can in the same way influence the biochemical factors in soils, and through them this balance of good and harmful properties.

When the dihydroxystearic acid has disappeared from the heated soil, through oxidation, cropping, liming, or use of nitrates, the full effect of the increased nitrogenous nutrients will manifest themselves and plant growth will be much better on the heated than on the unheated soil.

SUMMARY.

This bulletin deals with the chemical changes involved when soils are steam heated, as in the process of sterilization. The results may be summarized as follows:

(1) In accord with the work of other investigators it was found that there was an increase in water-soluble constituents and an increase in acidity. At the same time ammonia and amines were formed.

(2) By the process of heating there was an increase in all of the constituents isolated from the unheated soil except nucleic acid.

(3) By the process of heating there were formed xanthine, hypoxanthine, guanine, cytosine, and arginine, when not previously

existing. These compounds are decomposition products of nucleic acid and protein material and are all beneficial to plant growth.

(4) Guanine is reported for the first time as a constituent of soil organic matter.

(5) Dihydroxystearic acid was increased when present, and produced, when not previously present, by the heating process. This compound is harmful to plant growth.

(6) Both beneficial and harmful compounds were produced by heating the soils and were isolated. This bears out the experience of previous investigators with cultural tests.

(7) Cultural tests in these soils and their extracts showed that the heated soils gave a poorer plant growth.

(8) Although the majority of compounds formed must be classed as beneficial, the harmful compound formed at the same time more than overbalances their effects. Not until this harmful compound is eliminated or diminished can the full beneficial effects of heating be demonstrated.

(9) In soils there is a balance of beneficial and harmful factors, soil fertility or infertility being the resultant of the two groups. As one or the other group of factors gains the ascendency, the fertility is raised or lowered, as the case may be. This balance is influenced by cultural treatment, fertilizers, liming, crop growth, or crop rotation, etc., as well as by steaming.

(10) The results show that although the soils studied have received the same kind of organic matter and have received the same farm treatment, they have been subject to different biochemical factors, resulting in differences in their organic matter and in differences in their fertility.

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BUREAU OF SOILS—BULLETIN NO. 90.

MILTON WHITNEY, Chief of Bureau.

OCCURRENCE AND NATURE OF CARBONIZED MATERIAL IN SOILS.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., June 12, 1912.

Sir: I have the honor to transmit herewith the manuscript of a scientific paper entitled "Occurrence and Nature of Carbonized Material in Soils," by Dr. Oswald Schreiner and Mr. B. E. Brown, of this bureau. This paper is a contribution to the study of the organic matter of soils, and deals with the nature of certain processes in soils and the products resulting therefrom, and clearly demonstrates the wide distribution of carbonized material in soils. I recommend the publication of this paper as Bulletin No. 90 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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there appear even ponderable masses of organic material, usually black in color and capable of being distinctly seen with the naked eye. A much greater number of smaller though similar particles are seen under the microscope. It follows that an investigation of the soil organic matter is not complete unless this material insoluble in ordinary solvents is likewise taken into consideration, and if possible determining its origin or its formation in the soil. Owing to its insolubility the chemical nature of such material will probably be a difficult matter, but it should be possible to class it with other natural products by determining its prominent properties. In order to do this, particles of sufficient size to be readily observed must be obtained; that is, particles at least large enough to be visible to the naked eye and capable of being separated from the soil by mechanical means.

These larger particles, which make up a portion of the organic matter of the soil and which, in part at least, comprise that left intact by water or alkali, consist of material organized and unorganized. By organized material is meant that in which the original structure is still apparent, such as plant remains, insect parts, charcoal, lignite, etc. By unorganized material is meant that in which the original structure has been obliterated or so modified or changed as to be no longer visible, as in coallike particles, pitchlike masses, resin particles, etc. Both of these classes of material, organized and unorganized, while easiest recognized in the larger particles, occur nevertheless in smaller subdivisions in the soil. These smaller particles, however, especially in the absence of knowledge concerning the larger particles, do not lend themselves well to a study of their nature. In the present investigation the larger particles of soil organic matter were therefore the principal subject of study.

METHOD OF INVESTIGATION.

In the present investigation an attempt is made to gain some information concerning the nature of the insoluble organic matter of soils, especially the black particles so frequently encountered in the various soil separates obtained in the mechanical analysis of soils, as well as the particles observed after extraction with various solvents as before noted. In the mechanical analysis of soils the particles are separated into various grades, the silt and clay being removed from the more sandy particles and the latter separated by a series of sieves into five different grades. All of these separations show black or dark-colored particles which are organic in nature, as well as some black particles inorganic in character. In the coarse grades these particles can be separated by mechanical means or by means of liquids of such specific gravity that the minerals sink and the lighter par-